**Using life-cycle COST ASSESSMENT of fibre-reiNforced Automotive parts as a preliminary decision tool**

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**Abstract**

Fibre reinforced polymer composites provide several advantages over conventional materials, such as light-weighting potential, ability to produce complex shapes, and incorporation of smart functionalities. In the last few years, several research initiatives have accelerated development, addressing many of the challenges (material cost, production energy consumption, etc.) thus contributing to increasing adoption.

Despite overall market growth, adoption in sectors such as automotive has been somewhat slower. This is partly due to the limited understanding of the Life-Cycle Cost (LCC) performance – particularly at the End-of-Life – of such novel materials, and the increasingly stricter European regulations on the responsibility of OEMs over vehicle Life-Cycle (LC) performance.

The paper elaborates on a methodology for assessing the LCC of automotive modules. The methodology was developed within the ENLIGHT (Enhanced LIGHTweight Design) and ALLIANCE (AffordabLe LIghtweight Automobiles AlliaNCE) EC funded projects and is intended to be used as a preliminary decision tool for the choice of materials and manufacturing technologies at an early design stage. The paper presents the LC cost assessment by comparing the performance of a composite and a metal-based module.

Results show that although composite modules have siginifcantly higher material and manufacturing costs, they compensate with lower costs during the use stage due to lower fuel/energy consumption.

1. Introduction

Due to the continuous demands for safety, performance, comfort, and reliability among others, car mass has kept increasing in the past decades. In order to cope with the subsequent effects of more complex, and therefore heavier vehicles, lightweighting has been unanimously aknowledged as one of the key strategies due to its technical, economic and environmental advantges – such as cost and environmental impact reduction, performance and driving behaviour improvement, and easier handling of parts and components during production and maintenance activities [1,2,3].

Research and industry have proposed a broad series of innovative lightweighting solutions based on composites and hybrid materials. Many efforts though have typically failed to adequately and comprehensively address the related high cost issues. The excessive cost is caused by many factors, ranging from the high value of base materials, highly manually intensive processes and substantial capital investments in new machinery, to the added expenses resulting from the modification of well-established manufacturing, assembly and supply chain processes. However, the additional costs derived from lightweighting might be accepted by the end user if the total cost of ownership balances it (e.g. by life time fuel savings in case of conventional and hybrid drive trains, or similarly energy savings in the case of EVs). It can be stated that lightweighting is one of the most challenging tasks for modern automotive design [4,5,6]. The integration of lightweighting within the current design strategies requires an effective and affordable holistic approach able to process a great amount of information regarding performance, manufacturability, cost and eco-profile [7,8,9]. For this purpose, the design activities have to be supported by a systemic cost and sustainability assessment.

The present paper presents the ambition, framework and methodology developed for the Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) analysis of automotive parts, but focuses on the LCC results. In order to present the use of the developed methodology as a decision making tool, two door modules – a Fibre Reinforced Polymer (FRP)/aluminium lightweight version from the ENLIGHT project and a metal reference version from the ongoing ALLIANCE project – are analysed and compared. The overall scope is supporting decision-making on the choice of materials and manufacturing technologies at an early design phase, taking into account costs as well as environmental aspects during the entire LC of components.

1. Methodology

The LCC is an economic analysis used to estimate the total cost of a product or process throughout its LC, from production, to use, to EoL treatment [10]. It identifies and estimates all relevant costs attributable to the object of analysis. The LCC analysis supports decision-making by providing with a holistic estimation of the cost at an early design phase, which allows a more comprehensive and realistic comparison at all levels of the product’s life. Combined with an LCA analysis, it allows to assess the cost-effectiveness of the different options for a given application. Unlike LCA, there is no standardization of the methodology or a unique approach for the cost modelling of LC stages but only SETAC guidelines describing the main phases [11].

The LCC analysis is applied to both the reference metal-based (ALLIANCE) and the lightweight (ENLIGHT) door module, thus allowing a comparison between the two solutions. A specific and tailored modelling approach has been developed within the ALLIANCE project. In particular, the material, manufacturing, and use stages have been considered. Following a break-down approach presented in Figure 1, the full vehicle is divided into modules, which in turn are broken down into mono-material parts. The cost of mono-material parts is estimated according to their specific features (material type, part geometry, mass, volume, etc.) and the total cost of the module is obtained as the sum of the contribution of each mono-material part. Secondly, all the processes of module manufacturing are identified and broken down, including human and physical capital requirements (machinery, tooling, consumables, industrial space, employees, etc.) as well as their related costs; therefore the cost per part is estimated taking into consideration the inherent properties of the mono-material part and its specific manufacturing parameters. Finally, all costs per part are aggregated, including assembly processes (mono-material parts into modules, modules into vehicle assemblies) to obtain the total cost of the module. The cost of painting and final assembly is not taken into account, since it is not considered to be relevant for the final purpose of the task. In this study only the door module has been analysed, but some of the full vehicle parameters are taken into account in order to determine the cost of the use stage. For the lightweight module, a C-segment Electric Vehicle (EV) has been considered, whereas for the metal-based module an M-class Large Multi Purpose Internal Combustion Engine Vehicle (ICEV) has been used.



**Figure 1**. Breakdown approach for the production stage modelling.

The total cost of the module is built as the sum of several sub-costs, which in turn are function of a large number of parameters and variables that are considered in the global manufacturing process. The equations hereunder illustrate the comprehensive assessment of the manufacturing cost. The following equation displays the sub-costs that compose the total cost, thus showing the basis of the modelling approach.

*CostModule = CostMaterial + CostManufacturing + CostUse*  (1)

Where, *CostManufacturing = CostMachinery + CostTooling + CostConsumables + CostEnergy + CostLabour* (2)

And, *CostMaterial = Base price + CostMaterial processing* (3)

Where, *CostMaterial processing = f (Thickness, Width, Surface finishing)* and *Base Price = f (Mass)* (4)

Production cost is estimated for each mono-material part taking into consideration part geometry, material used, and manufacturing technology. For the reference door module, the production of the mono-material parts results from deep drawing, which in turn consists of a certain number of subsequent manufacturing steps, involving specific machinery, tooling and consumables. In the lightweight version, a combination of four manufacturing technologies (thermoforming, CFP, deep-drawing and casting) is considered.

The cost of use stage is based on the total amount of Fuel Consumption (FC) attributable to each module, taking into consideration the average EU-28 price for gasoline (2017) and electricity (2016). For both the ICEV and EV, the calculation of use stage consumption has been performed considering the New European Driving Cycle (NEDC).

Table 2 shows specific energy consumption and emission values used for the cost modelling.

**Table 2**. Energy consumption and emission values, for the environmental modelling (ICEV and EV)

|  |  |  |
| --- | --- | --- |
|  | **Vehicle and module technical features** | |
| **ICEV** | Vehicle fuel consumption (NEDC) | 6.29 l/100km |
| European emission standard | EURO 5 |
| Mileage use | 230000 km |
| **EV** | Energy MI | 0.69 kWh/100km\*100kg |
| Mileage use | 150000 km |

The Functional Unit (FU) is defined as the door module along a LC mileage of 230000 km (mounted on ICEV) and 150000 km (mounted on EV) over 10 years, respectively for the ALLIANCE and the ENLIGHT door module. System boundaries include all processes within the module LC stages presented in Figure 2.



**Figure 2**. LCA system boundaries of reference vehicle.

Transportation during manufacturing activities is excluded since specific information about logistic is not easily available; moreover, joining techniques among mono-material parts to modules are excluded. Vehicle maintenance is also not considered since it is regarded not relevant to the comparison.

The model can be divided into three main variable groups presented in Table 1; input variables (inherent to each mono-material part); model parameters; and assumptions, according to the data source and function in the model.

Table 2. LCC model variables and parameters

|  |  |  |
| --- | --- | --- |
| **Input variables** | **Model parameters** | **Assumptions** |
| Part geometry X, Y, Z[ m]  Box volume [m3]  Mass [kg]  Projected area [m2]  Material type  Manufacturing process | Energy consumption [MJ/kg]  Cycle time [s]  Scrap rate [%]  Cost of machinery [€]  Lifetime of machinery [years]  Cost of tooling [€]  Lifetime of tooling [years]  Cost of consumables [€]  Volume of consumables [kg] [items] [L]  Price of material [€/kg]  Employees [FTE] | Cost of electricity [€/kWh]  Cost of natural gas [€/kWh]  Cost of labour [€/h]  Annual production [vehicles/year]: target annual production volume for the project (100,000 vehicles/year). |

1. Results and discussion

Figure 4 reports the breakdown of LC costs for both the ALLIANCE and ENLIGHT door module, divided into material, manufacturing, and use stages. The EoL cost data gathered up to this stage were not considered sufficient to provide an adequately accurate estimation of the EoL costs, so they are excluded from this analysis. Figure 5 shows comparable results between ALLIANCE and ENLIGHT door module. For the ALLIANCE module the use cost has the highest contribution (55%) whereas for the lightweight version the highest share of costs comes from the material stage (66%). This is explained by the high cost of lightweight materials, particularly the CF cost, as well as due to lower energy consumption in the use stage. The significant difference between modules in terms of use phase contribution results from the difference in weight – which contributes to lower energy consumption – as well as the difference between the cost of electricity and gasoline.

**Figure 4**. Relative comparison of LC stages for the two modules

**Figure 5**. Absolute comparison of LC stages for the two modules

Overall, LCC results demonstrate that production cost (manufacturing plus material costs) has a significant contribution for both the ALLIANCE and ENLIGHT door module. Consequently, lightweight strategies should focus on the selection of materials and manufacturing processes in order to find a good balance between costs in the production and use stages, while decreasing overall LC cost.

In this study the LCC results are evaluated by means of the break-even analysis which allows: i) investigating the influence on results of LC mileage; ii) comparing results of door modules manufactured with composite and metal-based materials. This approach is generally used in order to evaluate the break-even LC mileage for which an innovative solution performs better in comparison to the reference one [12,13,14].

The graph in Figure 6 shows the break-even analysis in terms of cost assuming the NEDC driving cycle. The cost break-even point between the different door modules is at around 46000 km, as the production cost of the ENLIGHT door module is significantly higher due to the remarkable contribution of raw materials extraction and production.



**Figure 6**. Cost break-even analysis (NEDC)

3. Conclusions

The paper deals with results from both ENLIGHT and ALLIANCE projects. The outcomes of the cost assessment of the reference and lightweight door modules are presented and discussed. LCC results concern the first step of the lightweight strategy workflow developed within the ALLIANCE project where designers, materials and technology suppliers are involved to collect data necessary for the LC modelling.

In terms of cost, the break-even analysis shows that the lightweight door module compensates the higher production/acquisition cost at a fairly early point in the use stage, as soon as after the 46000 km mileage point is reached. It can be concluded that to reach environmental impact and cost reduction by means of innovative lightweight materials it is fundamental to bear in mind the potential trade-off between production and use stage.

It is worth mentioning that the results of the FRP manufacturing costs are lower than expected. That is because of a lower level of detail of the cost model for FRP parts compared to metal parts, mainly due to the scarce amount of data available in literature.

The next steps to increase the accuracy and usefulness of such an analysis is to futher increase the level of detail for FRP material and manufacturing data as well as define the EoL scenarios and their cost structure, so the EoL stage is included in the analysis.

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References

1. Keoleian, G. A., Sullivan, J. L., 2012. Materials challenges and opportunities for enhancing the sustainability of automobiles. MRS Bull 2012, 37 (April), 365−372.
2. Finkbeiner, M., Hoffmann, R., 2006. Application of Life Cycle Assessment for the Environmental Certificate of the Mercedes-Benz S-Class (7 pp). Int J Life Cycle Assessment 11, 240–246. doi:10.1065/lca2006.05.248 (2006).
3. Dubreuil, A., Bushi, L., Das, S., Tharumarajah, A., Gong, X., 2010. A comparative Life Cycle Assessment of Magnesium Front End Autoparts. Society of Automotive Engineers (SAE). DOI: 10.4271/2010-01-0275.
4. Dhingra, R., Das, S., 2014. Life Cycle energy and environmental evaluation of downsized vs. lightweight material automotive engines. Journal of Cleaner Production, 85 (2014) 347-358.
5. Das, S., 2005. Life Cycle Energy Impacts of Automotive Liftgate Inner. Resour. Conserv. Recycl. 2005, 43, 375 − 390.
6. Das, S., 2011. Life Cycle Assessment of Carbon Fiber-Reinforced Polymer Composites. Int. J. LCA 2011, 16, 268 − 282.
7. Cheah, L. W., 2010. Cars on a Diet: The Material and Energy Impacts of Passenger Vehicle Weight Reduction in the US; Massachusetts Institute of Technology: Cambridge, MA, 2010.
8. Kim, P.; Zukünftiger Fahrzeugleichtbau Werkstoffeinsatz im Umbruch, 1. VDI-Fachkonferenz “Leichtbaustrategien für den Automobilbau”, July 7-8, Ludwigsburg, 2011 www.project-alive.eu.
9. Bein, Th., Meschke, S. Innovativer Leichtbau durch Metalle und thermoplastische Faser-verbundwerkstoffe - Die EU-Projekte ALIVE und ENLIGHT, Proc. of the 9. Ranshofener Leichtmetalltage, November 9-10, Bad Ischl, 2011.
10. Swarr, T.E., Hunkeler, D., Klopffer,W., Pesonen, H.-L., Ciroth, A., Brent, A.C., Pagan, R., 2011. Environmental life-cycle costing: a code of practice. Int. J. Life Cycle Assess. 16, 389e391. http://dx.doi.org/10.1007/s11367-011-0287-5.
11. Hunkeler, D., Lichtenvort, K., Rebitzer, G., Ciroth, A., SETAC-Europe (Eds.), 2008. Environmental Life Cycle Costing. SETAC. CRC Press, Pensacola, Fla, Boca Raton.
12. Delogu M., Zanchi L., Dattilo C.A., Ierides M. (2018). Parameters affecting the sustainability trade-off between production and use stages in the automotive lightweight design. 25th CIRP Life Cycle Engineering (LCE) Conference (in press)
13. Witik, R.A., Payet, J., Michaud, V., Ludwig, C., Månson, J.-A.E., 2011. Assessing the life cycle costs and environmental performance of lightweight materials in automobile ap-plications. Compos. Part Appl. Sci. Manuf. 42, 1694–1709. doi:10.1016/j.compositesa.2011.07.024
14. Delogu, M., Zanchi, L., Maltese, S., Bonoli, A., Pierini, M., 2016. Environmental and economic life cycle assessment of a lightweight solution for an automotive component: A comparison between talc-filled and hollow glass microspheres-reinforced polymer composites. J. Clean. Prod. 139, 548–560. doi:10.1016/j.jclepro.2016.08.079