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Designing a new sustainable approach to the change for lightweight materials in structural components used in truck industry

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ABSTRACT

Reducing emissions and improving fuel economy are very important concerns for the heavy-duty transportation industry. Removing weight from vehicles increases performance and efficiency; this consequently lowers produced emissions and improves fuel consumption. For commercial vehicle manufacturers, the introduction of cost-competitive lightweight materials provides great potential to achieve these objectives. Ferrous cast materials, due to their high specific strength per cost ratio and flexibility to be used with casting processes are good alternatives to produce structural components, as weight savings can be achieved.

Numerous parts used in heavy-duty transportation vehicles need to be redesigned to fully take advantage of the increasing developments of metallic alloys. These materials with higher strength allow the reduction of part thickness while maintaining similar mechanical resistance properties. However, there are no established procedures that can help designers to reassess their previous projects and aid them in making new design decisions in order to achieve weight savings on heavy-duty vehicles. Vehicles of such nature are intensively used in ground transportation and are responsible for a considerable amount of emissions.

This work intends to create a novel procedure to help select and change the materials used for structural components of commercial vehicles, being certainly useful to alert and aid designers in updating their preexisting designs. Due to the complex geometry of the components utilized on cars, trucks and similar vehicles and regarding the strength requirements usually demanded by customers, casting processes assume a relevant status when considering the selection of the material/process combo to be used. Thus, a flow diagram was created containing relevant questions and answer paths, allowing the designer to easily re-think about the materials currently in use and bring to the discussion new materials and manufacturing processes. By introducing lightweight components in a more efficient way through well-selected materials alongside with contemplation of the manufacturing processes to be used, design engineers simultaneously enhance weight reduction; promote time savings, decrease energy consumption and achieve emission gains. As a case study, this work presents lightweight ferrous cast materials as a good weight reducing alternatives, as well as the procedure for materials selection for heavy-duty structural components.

1. Introduction

The automotive market is continuously growing, mainly in developed countries, having in 2012 surpassed over one billion cars in circulation all over the world, contributing with 27% of the total of CO_2 emissions (WWF, 2013). In the United Kingdom, around ¼ of the greenhouse gases came from the road transportation industry (UK Government, 2014). Some steps are being taken forward to prevent more severe environmental damages, namely by increasing the use of hybrid and electrical vehicles (Kastensson, 2014). However, these still feature several limitations such as low range autonomy and eventual environmental impact of batteries at the end of their life cycle. Indeed, environmental concerns regarding the impact of CO_2 emissions has become one of the most import issues for the automotive industry, along with safety and performance factors (Simões et al., 2016). However, this concern is not limited to automotive industry, being a concern as well for

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other types of fuel dependent means of transportations such as the naval or aviation industry (Huang et al., 2015). Nowadays, the perception of customers relatively to the achievements and efforts made by vehicle manufacturers plays an important role in competitiveness, being sometimes an influent factor on the consumer when making the decision of purchasing an automobile (Arena et al., 2013; Piccinno et al., 2015; Köhler and Som, 2014). In the last decade, some governmental actions (Schöggl et al., 2017) have been taken in an effort to motivate consumers to buy more efficient vehicles. This has been achieved by lowering overall acquisition cost fees, as well as circulation and fuel taxes, thus encouraging the customer's decision towards a more conscientious choice regarding environmental preservation.

Automobile producers have achieved reduction of pollutant emissions by utilizing diverse strategies, namely weight reduction (Mayyas et al., 2013; Raugei et al., 2015; Dhingra and Das, 2014; Simões et al., 2016). Effectively, there are some papers pointing out rough rules that take into account the effect of weight reduction in fuel consumption. Regarding the Swedish Association of Green Motorists (Swedish Association of Green Motorists, n.d.), a decrease of 5% fuel consumption can be achieved by each 100 kg of vehicle weight reduction. On the other hand, Kastensson (2014) refers, as a rule of thumb, that a fuel reduction of 4–6% is seen when a decrease of 10% in the vehicle mass is achieved.

Materials selection assumes an important role in the product definition and implies that Engineers and Designers accurately establish the main guidelines for the project, making the best choice in many selection conflicting situations, such as cost vs. lightweight, weight vs. robustness/durability, functionality vs. recyclability, among many others (Mayyas et al., 2013). However, if the materials selection is carried out in an early stage (laboratory), the costs are significantly lesser than when taken in further stages (in a plant or initial fabrication stage) (Köhler and Som, 2014).

In the case of smaller vehicles, weight reduction passes almost obligatorily by body material changes. Regarding commercial vehicles, room for improvement can be found in structural components. These parts constitute several devices related to the function of for instance buses, trucks or any other type of large commercial vehicles. In commercial vehicles, such as buses and trucks, there are many different parts used for peripheral functions which can be redesigned in order to achieve weight reduction.

Regarding specifically the truck market, the application of lightweight components is a crucial way to improve fuel economy and increase vehicle load capacity, improving transportation efficiency and consequently reducing emissions and increasing fuel savings. Topology optimisation and material research for materials with higher specific strength (higher strength to weight ratio) should be applied in order to meet mass reduction requirements, keeping or exceeding performance requirements and durability.

Low-density materials are extensively used in the automobile industry such as aluminium, magnesium, composite materials among others, to decrease mass by replacing ferrous alloys (Mayyas et al., 2016; Beyene et al., 2015). Design options and component applications may become strongly limited due to the higher cost and differences in specific modulus values, material strength, ductility and stiffness of these alloys. A456 T6 aluminium alloy is used in many applications due to its lowest cost among low-density alloys and good castability to produce thin wall sections. However, aluminium alloys are low-strength materials with roughly only one-third of the strength and young modulus of steel, besides having limited ductility (William et al., 2011). Material properties for cast structural components that equip heavy trucks are usually high tensile strength, high elongation and have the ability to cast thin wall sections and complex geometries (Hardeman, 2015). Ferrous alloys provide higher specific strength, young modulus and ductility with much lower cost per strength when compared with low-density alloys (William et al., 2011). Ultra-high strength cast ferrous alloys present a high strength to weight ratio. This characteristic is essential to produce structural components for commercial vehicles allowing the production of parts with thinner wall sections, decreasing the total weight of the component (Tekkaya et al., 2014). Fig. 1 shows the weight reduction potential by increasing the steel strength for the different load cases. For instance, according to Fig. 1, increasing the yield strength of steel from 200 to 550 MPa makes possible to have a component weight reducing up to 62.5% for structural parts.

For accurate comparisons, materials should be evaluated on performance per cost basis and not by weight per cost basis (Hardeman, 2015). Topology optimisation is used by the truck industry to create the exact casting geometry to withstand the service loads and stress-strain vectors, meaning the addition of material only in regions under high loads and removal in low stressed regions (Tekkaya et al., 2014). Hence, weight reducing can be obtained (William et al., 2011). Casting process gives the flexibility to produce complex geometries (Rimmer, 2014) allowing to reproduce the most efficient geometries obtained by topology optimisation.

Casting presents potential benefits regarding lightweight components by enabling the ability to produce complex shapes and thin wall sections (Rimmer, 2014). The design freedom provided by the casting process allows to reinforce parts in other ways rather than adding solid mass, like the use of ribbings (Gibbs, 2009). Some reports have shown the benefits of using the casting process for weight reduction when compared with forging or steel fabrication (Rimmer, 2014; Gibbs, 2009; Grede Casting Integrity, 2015). Therefore, this study was centred on cast ferrous alloys.

One of the goals for this work is to present high strength cast ferrous materials with weight reducing potential to be applied in structural components. Another objective is to present a material selection procedure for structural components of trucks to successfully produce lightweight components, enhancing mass reduction and consequently emissions and energy consumption decrease.

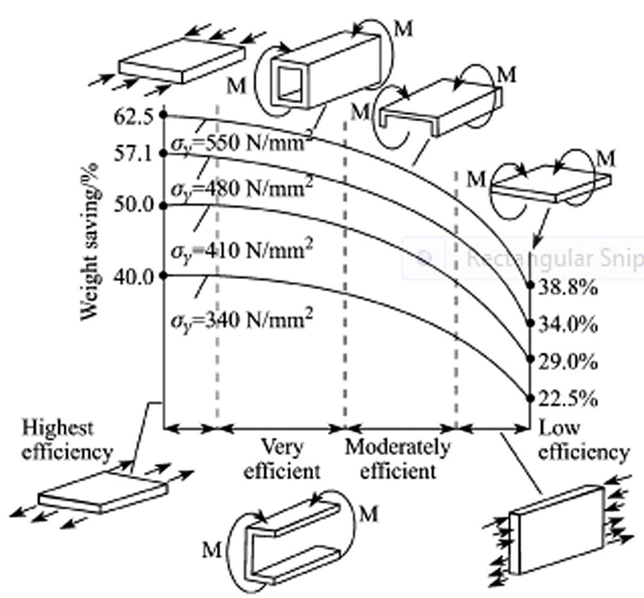

Fig. 1. Weight saving potential by replacing a 200 MPa yield strength steel with high strength steels for diverse loading conditions (Mohrbacher, 2013).