Graphene-based materials: opportunities for multifunctional lightweight structures in automotive sector

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Contribution brief summary:
The global automotive industry is currently facing great challenges, such as responsibility for increasing CO_2 emissions, lack of strong decarbonisation targets, and safety issues. It is also widely viewed as being the industry in which the greatest volume of advanced composite materials will be used in the future to produce light vehicles.
The study of novel composite materials, including graphene-based composites, and their potential applications in automotive industry, will be strategic for developing new lightweight and multifunctional structures for the automotive sector.

General Rules

The transportation sector is responsible of nearly one-third of global energy demand being the major source of pollution and greenhouse gas emissions in urban areas which opens the room for energy saving opportunities and clean technologies. The environmental sustainability represents one of the major driving forces for the innovation considering European Commission's regulation for CO_2 emissions which sets stringent values for fuel economy depending on the average fleet weight.
For EU average fleet, in 2020 the target is 95g CO_2/km and in 2025 75g CO_2/km which represents a great challenge for new materials and technologies; automotive OEM will have to pay a bill of 91€ for every gram of CO_2 emitted above the threshold which means more than 3000€ per car. This represents a strong driving force to new lightweight materials in order to help in decreasing CO_2 emission; based on preliminary calculations, every 10% of weight saving will bring to a 3-5% of fuel economy which can be translated into a price in the range of 3-5 € per kg saved.
The most promising way to enhance operating efficiency is the use of lighter structural and semi-structural materials including polymer-based materials as glass fibers and carbon fibers reinforced plastic (GFRP, CFRP).
Material selection depends on the performance requirements of a component's location and functional role in the automobile. These roles generally fall into one of three categories: body and exterior, interior, and powertrain. In the short term, lightening can be achieved by replacing heavy steel components with materials such as fiber-reinforced polymer composites. The properties and manufacturing of these materials are well established. In the longer term, even greater lightening is possible (50%–75% weight reduction for some components) through use of carbon-fiber-reinforced composites.
Advanced composite materials are viewed as a promising way to make vehicles more fuel-efficient and lightweight, but low-mass vehicles tend to perform less well in collisions.

The engineering strategy known as *Concept-oriented multifunctional lightweight design* results in the combination of light structures and multifunctional materials. However, significant hurdles remain with respect to improved performance, manufacturability, cost, and modelling for such materials [1]. As a consequence, considerable materials science effort and new discovery need to be developed to overcome these hurdles. The discovery Graphene with its interesting properties in terms of tensile strength and elastic modulus, electrical and thermal conductivity, thermal stability, gas barrier, and flame retardance has opened promising window for designing novel light composites while improving trade-off between lightweighting and safety issues. So new approaches must be found to enhance the crashworthiness of composites. Graphene composites may be able to fill that role [2].

The ***Graphene Flagship*** through one of its comprehensive tasks, the **i**nnovative **G**raphene-based Polymer **C**omposite materials for **Auto**motive ***iGCAuto*** applications, proposes to combine novel materials concepts with the latest safety design approaches through the development and optimization of advanced ultra-light Graphene-based polymer materials, efficient fabrication and manufacturing processes, and life-cycle analysis to reduce the environmental impact of future vehicles.
The present work provides an overview on Graphene Related materials (GRM) for automotive applications and investigates efficient ways to integrate Graphene as polymer reinforcements within composite materials for energy-efficient and safe vehicles (EESVs). The idea is based on the Concept-oriented multifunctional lightweight design aiming of combination of light structures with novel multifunctional materials. For such a purpose, GRM are addressed with respect to some challenging factors for instance the large scale production of Graphene or the non-existence of constitutive material models for high performance structural applications like crashworthiness. Therefore, accurate material models need to be developed to support simulation of structural design for these vehicles.

A focus on the hierarchical modelling of GRM with an emphasis on the multiscale constitutive behaviours of each material phase is elaborated in the framework of the Graphene Flagship to well understand such limitations for a full applicability of Graphene.

Minimizing costs is another key objective. EU Car Makers set the maximum cost allowed for mass reduction (in the range of 6-12 € for each kilogram saved). The cost of innovative lightweight materials employable in automotive sector have to consider this important factor.

Scores of additional applications emerge thinking of blending graphene-like structures (such as graphene, reduced graphene oxide and graphite nanoplatelets) with polymeric materials to improve existing properties or to provide new ones. The general aim is to investigate, to model, to design and to realize materials which have to be lighter, less expensive and recyclable, in order to improve safety and comfort into the vehicle. These goals can be reached by realizing multifunctional materials in order to include several functions inside a single material: in this way costs can be reduced and it is possible to produce a lighter material, easier to recycle too. The use of small amount of graphene-like structures as fillers in thermoplastics and thermosets permits to obtain new smart multifunctional lightweight nanocomposites with improved mechanical properties (in terms of crash performances, strength and dimensional stability), thermal behavior, flame retardance and electrical properties, paving the way to the substantial replacement of metals with plastics. Graphene-like structures are very good electrical conductors and they can form a conductive pathway that can be exploited in making electrically conductive filled composites. Initial indications are that lower loadings of graphene-like structures are required to reach a given level of conductivity than for any other conductive fillers. The opportunities for conductive thermoplastics, as well as thermosets, filled with graphene-like structures are wide.

Composites materials based on graphene like structures dispersed in insulating polymeric matrices are attracting a considerable interest for their use in polymeric and flexible electronics, electromagnetic and radiofrequency interference shielding (EMI/RFI) in electronic equipment, antistatic components to prevent static discharge in fuel systems, wiring, sensing and structural applications.

The realization of industrial components with multifunctional polymers will lead to a more compact environmentally friendly product characterized by a new electrical functionality, while an appealing design result in a high degree of integration and an intuitive user experience (new HMI concept). Therefore, the development of new plastic components not only improves perceived quality, but it will cause a reduction in weight and cabling, decreasing, as a consequence, CO_2 emission given by fuel consumption [3].

Multifunctional polymers with enhanced mechanical properties, electrically conductive and piezoresistive capabilities for integrated sensing and metal-free wirings will pave the way to a new generation of energy saving vehicles.

This initiative will impact on the quality of life: ultra-light vehicles will offer low energy consumption, and low CO_2 impact. The lightweighting of vehicles will accelerate their uptake in many market segments, and this in turn will have a direct positive impact especially on the quality of life in environments that today are suffering from excessive amounts of NOx and other unhealthy greenhouse gases (GHG), combined with excessive concentrations of diesel particles. The project will result in the development of the world’s first graphene-based polymer materials to be used in a large scale for vehicle bodies, in order to enhance their efficiency and safety standards. The results will benefit the automotive companies and relevant industries with optimised graphene-composite material properties in body parts, body-in-white, chassis and heavier interior systems. The development of novel materials will be of huge benefit to the global automotive industry. As the developed material could be used in several applications, the impact of the research will benefit a wide range of industry.

The main application targeted in this work is the automotive industry. This initiative also assures its impact in this sector by the inclusion of world-class academic and industrial partners within both automotive and materials sectors that, though focussing principally on passenger vehicle applications, will assure spin-off to their industrial vehicles affiliates. Higher performance composite parts offer a tremendous light-weighting benefit to transport vehicle sectors, of which automotive is by far the largest. Lightweighting is a top strategic and competitive priority for all transport vehicle industries, and cost effectiveness as well as industrialisation are key issues that remain as yet unsolved.

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Biosketch

Brunetto Martorana: graduated in Chemistry, Ph.D. in Materials Engineering. Visitor research student c/o Institute of Material Science - Polymer Program, University of Connecticut where he worked on polymer recycling. In CRF he manage the group “Polymers Innovation Plan” and he’s carrying out R&D activities about smart structures, methodologies for evaluating the environmental impact of nanomaterials, innovative adhesive systems, new coating with improved corrosion, scratch and UV resistance, new polymer-based composites for automotive applications. He's member of the Editorial Board of "International Journal of Automotive Composites". He's author of several patents and scientific papers.

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