The Implementation of Graphene Composites for Automotive: An Industrial Perspective

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Abstract. Graphene with its exceptional properties in particular the mechanical ones: strength and flexibility, has been found potentially applicable to improve performance of composite materials. Graphene composites is expected to be lighter yet provide more strength, much stronger than steel. This meets the growing demand in the automotive sector which requires lightweight as well as energy efficient and safe vehicles (EESVs) in order to reduce CO₂ emission and achieve more fuel economy of the vehicles. Hence, it is suggested to be applied in structural applications for automobiles. However, its scalability for massive production scale is still under investigation. It encounters challenges such as high manufacturing cost, feasible fabrication techniques, as well as safety issues. This study elaborates further the industrial perspectives on the implementation of graphene composites in automotive industry. The analysis in this study emphasises on three different aspects of innovation management: business ecosystem, PESTEL analysis, and scenario planning. The results of this study reveal key partners as well as potential competitors from the insights of business ecosystem, and two major concerns from PESTEL analysis and scenario planning: sustainable supply chains and quality of the graphene composites.

Keywords: Graphene composites; automotive industry; business ecosystem; PESTEL analysis; scenario planning

1. Introduction

The realm of nanotechnology and material science has today been more evolving with the advent of graphene. It is a single layer of atomic carbon generated from graphite materials and stacked into 2D (two-dimension) of hexagonal lattices [1]. This unique nanomaterial originates exceptional properties which possibly is the best characteristics of the substance derived from carbon. Albeit its thinnest physical structure and light in weight, graphene has been proved mechanically strong and resilient [2]. It also holds excellent electrical properties as its ultimately high charge carriers make it a prompted semiconductor [3]. As a result, it is potentially developed for the use in a wide range of applications such as electronics, photonics, energy storage, bio-applications and composite materials.

Despite its potentially broad applications, this study will particularly discuss the reinforcement of graphene in the polymer composite materials being applied in automotive industry. Automobile is one of the sectors that would mostly benefit from advanced composite materials [4]. In addition, it is reported that the recent common used materials for automotive applications is polymer composites [5]. However, the properties of polymer composites will be degraded over certain temperatures which
consequently will decrease their performance [6]. In that perspective, the intervention of graphene is believed would enhance the performance of the polymer composite materials and maintain the properties at their best. For this reason, graphene composites are developed to meet the growing market demands for light weight as well as energy efficient and safe vehicles (EESVs). The lower mass the vehicles hold, the less fuel and energy will they consume. Further positive impact will result in less emissions and thus more environmental friendly vehicles.

In addition, less amount of graphene as filler being reinforced in polymer matrices is considered will boost the properties of the composite materials much better than the current micron-scale filler [7]. Ideally, it could reduce the production cost for fewer substances required for the materials. However some challenges are faced in the innovation process. The production cost and scalability is one of the major concerns other than the complexity of the manufacturing techniques and deficiency in technology as well as the know-how for feasible commercial applications. Besides, the toxicity issue of graphene has not resolved and still under investigation.

Given these points, this study will provide an analysis on the development and the implementation of graphene composites for the structural applications in the automotive industry, particularly from the industrial perspective of innovation. The concept would cover three aspects: business ecosystem, PESTEL analysis, and scenario planning.

2. Graphene composites
The invention of graphene more than a decade ago by two scientists from University of Manchester has grown confidence in a better advanced composite materials through the dispersion of that so-called ‘wonder material’. It is categorised as a potentially disruptive technology that could initiate a new industry and replace all other existing materials owing to its incredible properties [8]. In spite of being doubted at the initial stage to have influence in the market, it will gradually enhance its market share by supplementing other materials, eventually become a complete substitution for those other substances such as silicon or steel, and then shift the market. On the contrary, staying merely in the realm of laboratory and not proceeding to the commercialisation stage might frightfully lead to discontinuous innovation, futile invention of the incredible material, regardless of wondrous properties it holds.

According to the theory suggested by Elmarakbi, the reinforcement of graphene in the composite materials used for auto structural application could reduce weight up to 50% [9]. Graphene is not only to reduce weight, but also to enhance strength, durability, flexibility, transparency, thermal and electrical conductivity. A multi power resides in one single material. It can be tailored to the specific requirements of the intended applications, including the structural ones for automobiles.

However, there are also several challenges in the manufacturing of graphene composites for vehicles, such as limited studies on the process of graphene-polymer melt blending [10], feasibility on its economies of scale, environmental impact, and safety issues.

3. Business Ecosystem
Several leading auto companies were included as the centre point in this environment, as depicted in Figure 1. For instances, General Motors (GM) has been acknowledged as the first automaker to produce commercial car components with Nano clays as the filler [11]. Thus, they could be key partners to one another, or else have intense rivalry among them. Furthermore, the ecosystem shows how the firms interconnect with other stakeholders to support the implementation of graphene composites for automobiles.

3.1. Graphene composites manufacturers
These companies producing graphene composites are crucial as they will be the suppliers for the auto companies to realise EESVs. A strategic alliance can be established between companies in which technology and knowledge sharing would benefit those involved in the process.
3.2. Research and development (R&D)
It is a problem solver particularly for technical issues, as well as to prepare the technology readiness for the mass production of graphene composites.

3.3. Funding institutions/investors
They are beneficial in order to support the finance of the groups, especially to help ignite and flourish this immature industry of graphene composites.

3.4. IP and consultancy
It is involved in the process of filing patents or obtaining feedbacks related the development of graphene composites, including the market demand for the EESVs.

3.5. Infrastructure
This is including facilities for manufacturing and recycling process to support the operational activities.

3.6. Regulation and policy maker
It is a compulsory for the players to comply with laws and regulations associated with their businesses.

3.7. Standardisation
It is an extremely important issue to address so that the companies know how to improve the quality of the products, both graphene composites as the material and EESVs as the end products.

4. PESTEL analysis
Table 1 shows a short-list of variables that have been taken into account in order to anticipate opportunities as well as threats that might occur in the future related to the implementation of graphene composites on vehicle production. They were examined based on the scale of importance and uncertainty. The highlighted items are the most important and uncertain issues that would formulate the scenario planning.
Table 1. PESTEL analysis

| POLITICAL                                                                 | ECONOMIC                                      | SOCIAL                                         |
|--------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------|
| “Brexit” towards the trade and investment on graphene composites         | Manufacturing cost                            | More affordable cars                           |
| Private-public partnership on graphene development                       | Sustainable supply chains                     | Higher congestion                              |
| Regulation on clean and safety transport                                 | Exchange rate fluctuations                    | Increasing awareness of environmental impacts  |
| Standardisation                                                          | Global economic conditions                     | Supporting the idea of smart transport         |
|                                                                           | Applicability for mass production scale       |                                                 |
|                                                                           | Market maturity                                |                                                 |
|                                                                           | Economic growth                                |                                                 |
|                                                                           | Funding and investment                         |                                                 |
|                                                                           |                                               |                                                 |
| TECHNOLOGICAL                                                            | ENVIRONMENTAL                                  | LEGAL                                          |
| Technological readiness                                                  | Reducing CO₂ emission                         | Safety insurance                               |
| Technology transfer                                                      | Non-hazardous material (REACH)                | Product safety                                 |
| Knowledge transfer                                                       | Energy efficiency                             | Certification                                  |
| Skilled manpower                                                         | The exploitation of graphite mining           |                                                 |
| The emergence of other 2D materials                                      | Recyclability                                  |                                                 |
| Vehicles safety and performance                                          |                                               |                                                 |
| Manufacturing techniques                                                 |                                               |                                                 |
| Composites quality                                                       |                                               |                                                 |
|                                                                           |                                               |                                                 |

5. Scenario planning

The result of the two most important and uncertain issues from the PESTEL analysis is represented by two axes and converted as the input for scenario planning. The matrix is illustrated in Figure 2.
It can be seen that the sustainability of supply chains and the quality of graphene composites were considered highly important and uncertain in this study. Sustainability is essential to ensure the scalability of the production process and affordability of the material, yet it is uncertain due to immature market and technical issues on production scale. On the other hand, the quality of composites will definitely determine its performance on the end applications. As a matter of facts, the quality highly depends on the fabrication process of the material, and it is still under extensive research in numerous projects.

Those two main issues lead to four conceivable trends with respective consequences that might occur in the forthcoming years. Each of the scenarios was given different label to highlight the condition: graphene world as the ideal one (sustainable and high quality); price tag (unsustainable but high quality); despicable me (sustainable but low quality); and suicide lines (unsustainable and low quality).

6. Conclusions
The implementation of graphene composites on the commercial applications particularly automotive has been in immature stages yet considerably challenging to be overcome. The analysis on business ecosystem showed key partners or instead competitors along with other stakeholders in applying graphene composites for vehicles. Meanwhile, a strategic analysis based on PESTEL variables revealed two major concerns in this industry: sustainability of supply chains and quality of graphene composites. Finally, it leads to four scenarios with respective effects that might occur and be anticipated in the future: graphene world, price tag, despicable me, and suicide lines.

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