USE OF GRAPHENE IN SHEET MOLDING COMPOUND (SMC) FOR APPLICATIONS IN ELECTRIC VEHICLES

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Abstract

The interest in electric vehicles has grown recently due to concerns over air pollutants emissions contributing to sustainable development. Establishing the transition from conventional combustion engines to electric powertrains reduces fossil fuel consumption and noise pollution due to their silent electric motors. In this context, composite materials became a great ally in performing the motor transition, as they combine mechanical resistance with lightness using innovative structural designs. The sheet molding compound (SMC) is an economical product that consists of a mixture of fiberglass, additives, catalysts, and mineral fillers embedded in an unsaturated resin. To improve the structural properties and reduce the weight, nanomaterials such as graphene can be added to the manufacturing process resulting in a significant increase in mechanical properties, stiffness, shear strength, and modulus, demonstrating superior properties to traditional parts and providing good technical processing feasibility, consequently generating new materials. It may be used to replace conventional materials when applied in polymeric composites, such as metallic and other polymeric materials existing in vehicles. From this innovative perspective, the incorporation of graphene enhances the composite's performance by achieving weight reduction without loss of properties for structural and non-structural applications, particularly to electric vehicles.

Introduction

As the global trends move towards decreasing CO_2 emissions and reducing oil consumption, vehicle electrification gained notable visibility for its environmental benefits and development of energy-management strategies, achieving an industrial leadership position in advanced technologies [1] [2]. The transition from conventional fossil fuels-based vehicles to electric ones helps to reduce gaseous pollutants emissions, such as carbon monoxide (CO), nitrogen oxides (NO_x), sulfur dioxide (SO_2), and volatile organic compounds (VOC_s) [3].

Nowadays, there are over 30 models of electric vehicles (EVs) in the automotive industry, with new models under development [4]. One of the automotive engineers' biggest challenges is to significantly reduce structural parts weight and develop lightweight materials. Automobiles' weight is typically over 63% metallic, a 10% weight reduction in conventional vehicles could increase the fuel saving by 6–8% for internal combustion engines and 10% for electric vehicles [5] [6]. Lightweight can be achieved by material substitution (e.g. metal being replaced with polymers or composites) coupled with systems-engineering component redesign without compromising the size and capacity of the vehicles [7] [8].

In this context, composite materials have been largely employed in automotive applications all over the years, becoming a great ally in the electric revolution due to their lightness, flexibility and low cost, combining mechanical resistance through innovative and structural designs [9] [10].

Molding compounds are plastic materials with different stages of granulation [4], produced by a combination of fibers as reinforcement (glass, carbon, or aramid fibers) with mineral fillers (mica, calcium carbonate, clay), embedded in a thermosetting resin (vinyl ester, modified vinyl urethane, phenolic and unsaturated polyester) mixed with other additives [11]. These materials are manufactured by thermo-mechanical loadings associated with chemical reactions [12].

SMC materials are applied in the automotive industry as ideal candidates for semi-structural components due to their high strength-to-weight ratio, corrosion resistance, flexibility and parts consolidation [13]. Currently, these materials are the most popular because of their low cost as well as their molding efficiency [14].

Methodology Review

Classical SMCs consist of continuous sheets of chopped fibers with mineral fillers mixed in a thermosetting resin. Typical composition might consist of 25% unsaturated polyester resin, 25% glass fiber and 50% filler [9] [15]. The method for processing SMCs consists of plies cut in desired shapes and size, to be handled in a preheated mold [16]. The metal molds are heated in a range of 266°F to 320°F, mounted on large hydraulic or mechanical molding presses [17].

This process is accomplished by adding a thickening agent, such as divalent cations, that combines chemical reactions to produce a thickened, non-flowing resin, forming a charge [16]. The basic process of sheet molding compound is shown at Figure 1.

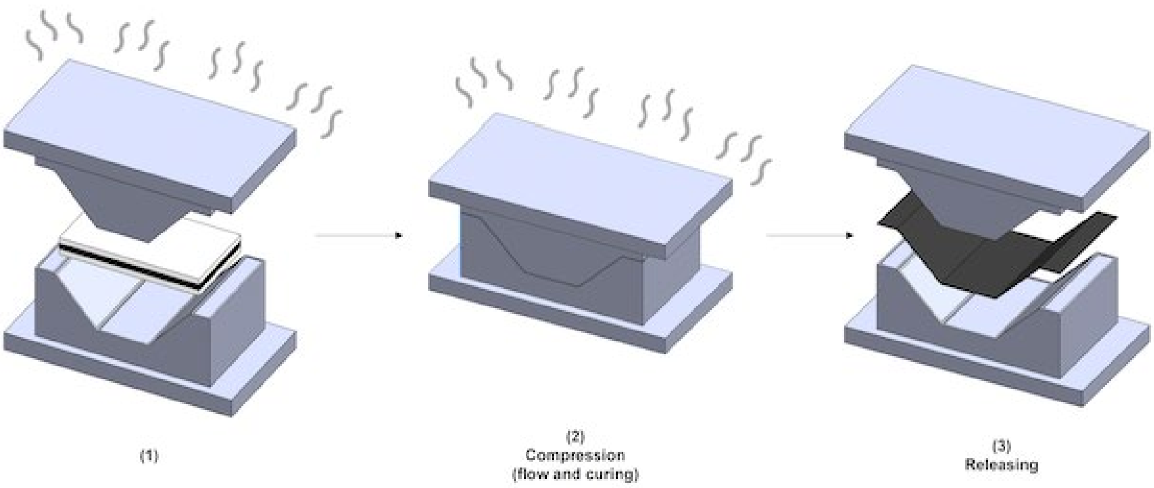

Figure 1: The sheet molding compression process. Adapted [14].

The charge is placed into a mold and, when pressure builds up, the material is forced towards the outer edges of the mold, where a narrow vent is formed, letting the air escape and trapping the SMC. The pressure is kept until a degree of curing is achieved, forming the structure. This allows flow and welding of the sheets, followed by free radical curing reactions at high temperatures. Indeed, it is essential to notice that during the forming of the part, the SMC charge is not only stamped but flows [16]. Depending on the model and part size, the force applied by the press can reach up to several hundred tons, being very useful to obtain good part uniformity, avoiding obstacles in process such as shrinkage and surface defects [14] [18] [10].

The major advantage of these materials is that their formulation can be tailored to meet the requirements of diverse range of applications, allowing to process complex and large shapes on a rapid cycle time [19]. The Table I presents some SMC composites formulation, other publications also mention the use of natural fibers (e.g flex, abaca, jute) instead of glass and carbon, as an optional reinforcing element. [20] [17].

Table I: Formulation of sheet molding compound composites

Formulation of Sheet Molding Compound composites		
Polymer Matrix	**Reinforcing Fiber**	**Reference**
Vinyl ester	Carbon fiber (53%)	[21]
Vinyl ester	Carbon fiber	[22]
Epoxy	Chopped carbon fiber	[23]
Polyester	Glass fiber Carbon fiber	[24]
Vinyl ester	Glass fiber (50%)	[25]
Epoxy	Glass fiber (25% and 50%)	[26]
Vinyl ester	Carbon fiber (43%)	[10]
Polyester	Glass fiber (25%)	[9]
Vinyl ester	Chopped glass fiber (50%)	[27]
Unsaturated Polyester Vinyl ester	Glass fiber (30% and 25%)	[11]
Epoxy	Carbon fiber	[28]

In the automotive and truck industries, SMC parts are used notably in exterior and interior of body panels, painted (Class A parts), and unpainted, semi-structural, and structural parts [19]. Some parts of interest are reinforcement for liftgate, doors, hoods, roof and pick up boxes as can be seen in Figure 2.

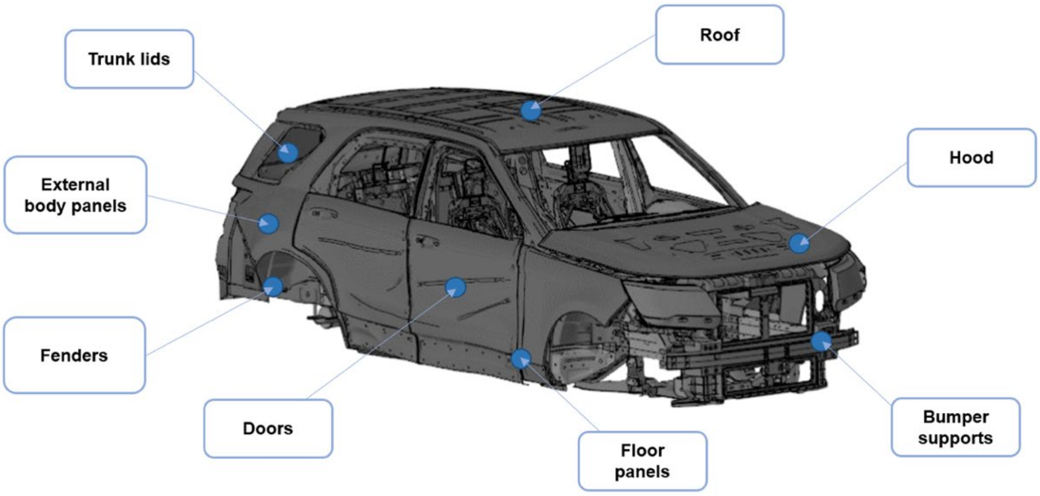

Figure 2: SMC Structural parts.

The introduction of nanomaterials into composites formulation can deeply modify properties of SMC. Engineers have been working on adapting nanoscale material such as graphene and graphene-related material (GRMs), graphene oxide (GO), reduced graphene oxide (rGO) or functionalized graphene (f-Gr) into the polymer matrices [4].

Graphene is the basic structural element of other allotropes of carbon, including graphite, charcoal, carbon nanotubes and fullerenes [29]. Discovered just over a decade ago, its unique 2D isotropic structure with sp^2 hybridized carbon atoms are perfectly displayed in a hexagonal honeycomb shape, with 0.1 nm of distance between each atom and 0.3 nm of thickness [30] [31].

Transparent and flexible, its chemical structure allows to share its exceptional mechanical, thermal, electrical and optical properties with other materials [32]. Graphene has a set of exceptional properties, highlighted in Table II.

Table II: Properties of graphene [4]

Properties of Graphene	
Tensile Strength	130.5 GPa
Young Modulus	1 TPa
Thermal Conductivity	4840 W/mK
Electrical Conductivity	2000 S/cm
Surface Area	2.630 $m^2.g^{-1}$

In view of that, graphene market is extensively growing. Companies tested graphene-reinforced foam covers for noisy components such as the fuel rail, pumps, and belt-driven pulleys or chain-driven gears on the front of engines. The material was mixed with foam constituents, and the resulting parts are said to be 17% quieter, 20% stronger, and 30% more heat-resistant [33].

The number of studies related to the application of graphene in SMC compounds in the automotive industry has increased in recent years, showing exponential growth from 2019 to 2021. This is also reflected in the innovation of the electrical cars industry. In a survey carried out on the Espacenet database using the keywords *sheet molding compound, graphene, automotive*, it was observed that 2021 was the year with the highest number of patents filed – 26 patents, following the trend observed in the number of scientific publications (Figure 3) [34]. Despite this, studies on the addition of graphene in SMC composites are still limited in the literature.

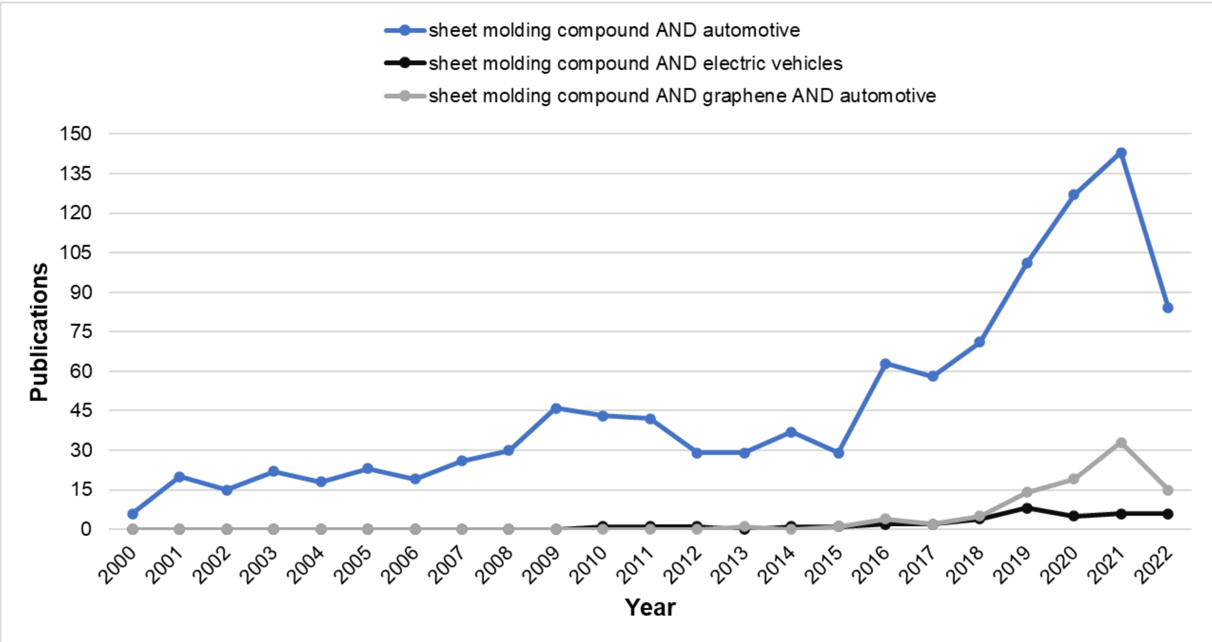

Figure 3: Publication trend from the year 2000 to 2022 according to Scopus (June 2022) [35].

The application of graphene in the manufacturing process of SMC materials can improve structural and mechanical properties as tensile and flexural strength that can be enhanced by adding a small amount of graphene into a polymer of fiber-reinforced composite system. University researchers have demonstrated that when just a 3% loading of GNPs is added to a standard sheet moulding compound (SMC) formulation, the resulting composite is stronger by 40%, stiffer by 20% and demonstrates a massive 80% increase in impact strength [36]. Therefore, the design based on graphene-based SMC composite material and manufacturing method is very necessary.

Results

The patent search was first performed using the keywords associated with the Boolean operator *sheet molding compound* and *automotive*. On the Google Patents platform – which includes publications from the Patent and Utility Model Databases of several countries, such as the United States Patent and Trademark Office (USPTO), Japan Patent Office (JPA), Russian Patent Office (ROSPATENT), and World

Intellectual Property Organization (WIPO) – a total of 14.023 results were found [37]. Of this total, 5.155 patents have already been granted. In the Espacenet database, 2.043 results were found, with the United States (US), Japan (JP), and Germany (DE) being the main depositor countries [34]. With the same keywords, 399 results were found on the PatentScout platform – 96 patents are active [38]. Using the research data and the tools of the platform, it was possible to obtain the subclassification of patents, composed of 108 groups. Figure 4 brings this subclassification and the description of some groups of patents [39].

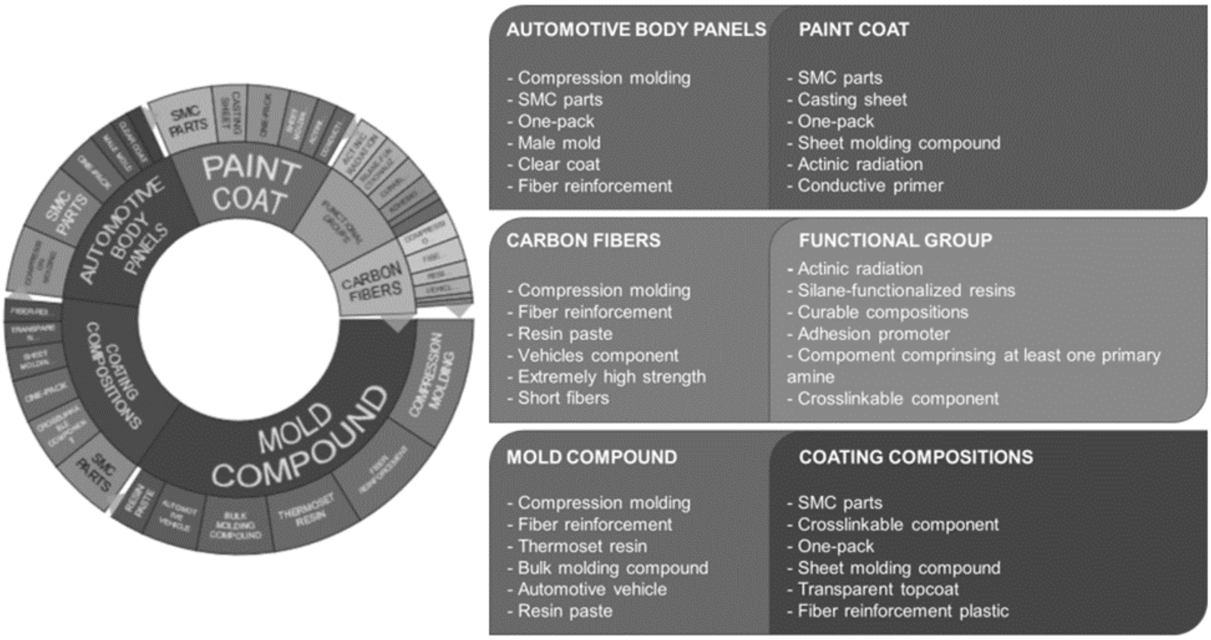

Figure 4: Patent subclassification is composed of 108 groups. Data obtained from research data on the PatentScout platform (June 2022) [39].

In the search using the keywords *sheet molding compound* and *electric vehicle*, carried out on the Google Patents platform, 168 results were found. Of this total, 93 patents have already been granted [37]. In the Espacenet database, 155 results were found, with South Korea (KR), the United States (US), and Japan (JP) being the main depositor countries. With the same keywords, 15 results were found on the PatentScout platform, with 8 patents being active [38].

In ordered to analyze the world scenario on the use of graphene in the process the keyword *graphene* was included in the research carried out previously. With the keywords *sheet molding compound*, *electric vehicles* and *graphene*, the number of results found – scientific publications and patents – was significantly reduced. The Google Patents platform search returned 17 results for the combination. On Espacenet 20 results were found [34].

In this context, the current scenario regarding the addition of graphene in SMC manufacturing composition is more significant among patents. The following inventions cover a variety of aspects of using graphene prepregs to improve mechanical properties by adding a small amount of graphene in epoxy, glass filled or, as sizing on carbon fibers.

A published study showed that the incorporation of (0.05-1% by weight) of graphene in fiber filled SMC, improved the mechanical properties such as Izod impact strength, flexural strength and tensile properties. These parts were stronger than other like parts and therefore lighter weight sturdier parts such as hoods, tops, fenders, trunk lids and liftgates allowing manufacture of lightweight and robust structural vehicle parts [28]

The invention *CN112980210A,* presents a graphene-based SMC composite and its preparation method by a mixture of fiberglass, unsaturated resin, graphene, anchors and additives in the manufacturing method. The addition of graphene promoted an improvement in mechanical performance, in addition to increasing scratch resistance, compensating the defects of the SMC, such as fragility and the formation of microcracks and voids, promoting toughness and high strength. The document was filed in 2019 by the same Chinese Company as the aforementioned patent [40].

CN112977308A described an automobile bumper of SMC composite material based on graphene, that prevent dust and external particles from entering through the bumper, prolonging the life of the part and enhancing the impact protection effect, through an anti-pressure graphene layer, an adhesive layer and a polymer sheet layer, promoting toughness and reducing the abrasion in the set. The document was deposited in 2019 by a Chinese Company [41].

The invention *US2020165410A1* describes an electrically conductive SMC composite, with improved properties by application of graphene nanoplatelets and describes the method of manufacturing. The main component of the SMC composite formulation is a polymer resin mixture with graphene nanoplatelet charges (0%, 1.72 wt%, 2.80 wt%, and 4 wt%). Properties such as the Storage Module and the Flexion Module, for example, were directly proportional to a load of graphene nanoplatelets added to the matrix, representing a potentiation of these properties. Among the proportions tested, it was concluded that the formulation containing 4 wt% of GnP presented the best potential in electrical conductivity. The SMC compound was presented as a possibility for fast manufacturing of vehicle parts, such as bumper beams, vehicle door panel components, automotive floor components, recreational vehicle panels, spoilers, and hoods [42].

Up to now, only few researches has been conducted on the fabrication of SMC composites using graphene and its derivatives, most of the studies are based on the area of matrix modification by GNT with remarkable outcomes. Graphene's applications can improve structural and mechanical properties as tensile and flexural strength giving a better performance to SMC composites.

Summary and Next Steps

The present work presented an overview regarding the use of sheet molding compounds by the compression molding manufacturing process in automotive industry. The search for lighter structural components with improved properties and each application, is a reality in several sectors. Given that a lighter package results in fuel savings and, for electric vehicles, offsets the weight of power and control systems, increasing autonomy and improving efficiency. The use of SMC composites reinforced with fiberglass and/or carbon fiber is an approach already widespread as a fast and widely applicable option in the manufacture of automotive components. In order to promote processing improvements and enhance properties such as flexural strength, impact strength, Young's modulus and electrical conductivity, the application of alternative materials as additives in SMC composites is an attractive possibility. Graphene presents itself as a relevant option for this, due to its versatility and its improved properties, already documented in the literature for similar applications. A few applications of graphene in SMC composites are already described as a form of intellectual property. In this scenario, it is understood that one of the challenges for the industry is in defining the ideal formulations for each type of application. Studies on the subject are necessary, given that there is little information described in the scientific community.

Acknowledgements

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