# Graphene Infused Elastomer Nanocomposites: Materials for Improving Food Packaging

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## Introduction

**The Importance of Food Packaging**: Continually expanding the knowledge of what materials make the safest, most effective, and cheapest food packaging allows for the development of food production and transportation systems that are better able to address the needs of an ever expanding population. In particular, the compound graphene is especially promising as an additive to traditional elastomers to yield graphene infused elastomer nanocomposites (GIENs). The newly synthesized compounds have promising applications in the food packaging industry due to their unique structure and desirable permeability properties.

**The Food Packaging Industry Today**

Properties of desirable food packaging

- Ability to resist puncture deformation
- Slow rate of fatigue crack growth
- High tensile strength
- Low moisture and gas permeability
- Low production cost

(a) (b) (c)

**Figure 1.** (a) Polyethylene: Most common elastomer used in industry. (b) Polypropylene: Sees widespread use as a because it is cheap and microwave safe. (c) Polystyrene: Used for it insulating food and retaining heat.

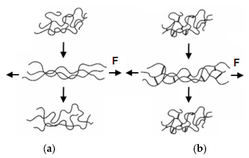


**Figure 2.** a) A typical polymer. After the stress is applied (middle image), the polymer recovers somewhat, but significant deformation remains. (b) A typical elastomer. After the stress is applied, the cross-links allow the original shape to be fully recovered.

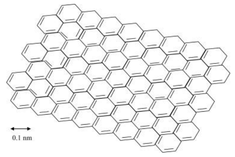


**Figure 3.** Structural diagram of graphene (carbon atoms are represented by vertices of the hexagonal lattice).

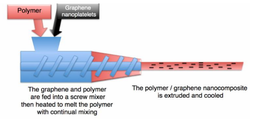


**Figure 4.** A shear mixer, in which the solid graphene is mixed into the liquid elastomer via

## GIEN Materials and Synthesis

- Elastomers are a specific type of polymer in which the molecular chains are "cross-linked" by smaller chains, giving them increased elasticity[1] (Fig. 2b)
- The ultimate strength of a material depends on the elastic modulus (ability to resist tensile strain) and can be greatly improved with the incorporation of a filler such as graphene
- Graphene is a planar (two-dimensional) sheet of $sp^2$ hybridized carbon atoms arrayed in a hexagonal structure[2] (Fig. 3)
- Graphene has an elastic modulus of ~1 TPa (approx. 20.89 billion lbs/ft$^2$), five times more inelastic than steel[2]
- These two materials can be combined to form GIENs through two different processes: melt mixing and solution blending (Table 1)

| Melt Mixing | Solution Blending |
|---|---|
| Already used in industry to disperse carbon nanotubes into polymers | Most popular method for producing GIENs in a research setting |
| Elastomer is melted down, then solid graphene is mixed in (Fig. 4) | Both components are dissolved in solution and mixed through ultrasonication |
| Elastomers may be too viscous to allow even distribution | At present, moving to industry scale would be expensive and inefficient |

**Table 1.** Comparison of the two methods used for GIEN synthesis[3] (possible advantages tinted green, possible disadvantages tinted red).

## Structural Properties of GIENs

- **Reduced Fatigue Crack Growth[4]**
  - Graphene's miniscule volume per unit mass helps it resist the formation and expansion of fatigue cracks
  - Reduces the volume of packaging needed to adequately package food
  - Increases resistance to physical stress
- **Increased Tensile Strength[5]**
  - The extremely high elastic modulus of graphene reduces the effect that tension forces have on the material
  - Reduces the amount of tearing and stretching due to gravity
  - A resistance to gravitational tension forces could open the door to new, more efficient methods of food storage.

## Permeability Properties of GIENs

- The "hedge maze" like effect of Graphene in GIENs greatly reduces the gas permeability of all gases through the material
- The low permeability has different repercussions on GIEN's applications in food packaging depending on the identity of the gas
  - **In regards to $H_2O$**
    - Low $H_2O$ levels inside of food packaging will inhibit the growth of bacterial and fungal species that will damage the food, because of this, low $H_2O$ permeability has the effect of increasing the shelf-life of the packaged food[6]
  - **In regard to $O_2$**
    - Reactive oxygen gas is what causes the oxidation of organic fruits and vegetables. This process is what eventually leads to their spoiling. Reducing the concentration of $O_2$ within the packaging will reduce the rate at which this reaction occurs and increase the edible lifespan of the food[7]
  - **In regards to $N_2$**
    - Nitrogen gas in highly unreactive, so a controlled atmosphere with a very high nitrogen content is ideal for maximizing the shelf life of food products. The low permeability of GIENs will allow the package to retain the gases it was packaged with longer, thus expanding the potential of controlled atmosphere packaging[8]

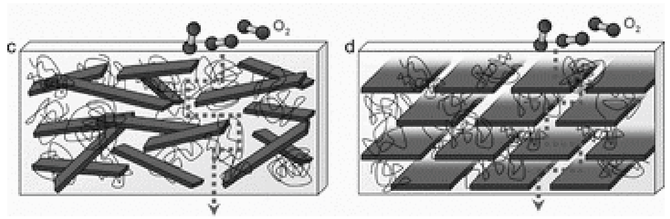


**Figure 5.** Demonstration of how the addition of graphene (the dark rectangles) inhibit the path of gas molecules (dotted line) by acting as a sort of "hedge maze", drastically increasing path length of gas molecules

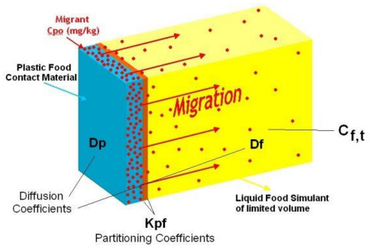


**Figure 6.** Visual representation of the migration of packaging particles (red circles) into the food (yellow). This can lead to undesirable effects such as rancidification of fats, oxidation of produce, spoiling of dairy etc. It is not conclusive what effects GIENs may cause, but in any case, migration should be minimized.

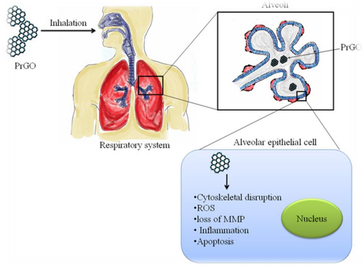


**Figure 7.** Airborne graphene is small enough to enter deep into the lung, where it embeds itself in the alveolar wall, causing inflammation or even cell death. The body's only method of purging it is filtering the particles to the lymphatic system, which can take weeks.

## Possible Health Hazards

- A major concern of any packaging material is its tendency to "migrate", the term for the movement of small particles that have flaked off the packaging into the food
- Conclusive data for GIENs are not currently available because the technology required to accurately measure migration, called inductively coupled plasma analysis (ICP), was not available until very recently, however early tests show relatively low migration levels[9]
- Graphene may pose a respiratory risk, as it belongs to a group of compounds called aromatics, many of which are carcinogens
- Because graphene is chemically inert, the body lacks the mechanisms both to prevent GIENs from settling in the alveolar walls of the lung and to break it down once there[10]
- These results are not conclusive, and more research must be done to definitively determine risks posed by GIENs

## Conclusions

- In terms of functionality, graphene infused elastomer nanocomposites are perfect for food packaging, as they provide vastly increased tensile strength and moisture impermeability that will allow food packaging to better weather the rigors of transport and storage
- However, the methods used to produce GIENs remain untested on industry scales, and in their current form are predicted to be expensive and inefficient; more importantly, valid concerns remain about the safety of using GIENs as food packaging
- If GIENs are to be phased in as a next generation food packaging, the following must occur:
  - More research needs to be done to definitively quantify health risks
  - New, cheaper methods must be developed for production, or old ones modified
  - The improvement in quality must be significant enough to capture public interest

## Acknowledgements

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