

## EVALUATION OF GRAPHENE INCORPORATION FOR MECHANICAL PROPERTIES OF POLYPROPYLENE COMPOSITES

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**Abstract** - Graphene nanoparticles (GnP) was selected as an alternative reinforcement, nanofillers, to enhance the mechanical properties of polypropylene (PP-homo and PP-copolymer) and using compatibilizer, maleic anhydride graphitized with polypropylene (PP-g-MA) in a twin-screw extruder. The effect of GnP loading and the use of the PP-g-MA compatibilizer were studied. The influence on the mechanical properties of tensile strength, elongation, IZOD impact strength, and melting temperature in PP-homo and PP-copolymer were investigated and compared. Their improvement was observed up to a certain amount, depending on whether it is a homopolymer or copolymer. The PP copolymer has a greater affinity with graphene and the compatibilizer due to the elastomeric comonomer present in the copolymer.

**Keywords:** *graphene nanoparticles, polypropylene, homopolymer, copolymer.*

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### Introduction

A graphene nanoparticle (GnP) is a single layer of carbon atoms packed into a honeycomb structure [1]. Following the independent discovery of graphene in 2004, a revolutionary amount of research was conducted to fully exploit graphene's exceptional properties. GnPs are graphene nanocrystals layered in the structure of platelets stacked by Van der Waal forces. The incorporation of GnPs in conventional polyolefins has promising potential in a wide range of applications due to their excellent thermal, mechanical, and electrical properties. Such composites can be employed in the fields of electronics, automotive, aerospace, sensors, and much more. Among many polymers, polypropylene (PP) is one of the most widely used thermoplastics due to its excellent physical and mechanical properties, chemical resistance, recyclability, high processability, and low cost [2]. The PP application field includes packaging, textiles (ropes and mats), automotive components, etc.

Due to the high potential of PP composites incorporated with GnPs, researchers extensively study the various properties of these materials, the performance of the composites is highly dependent on the physical characteristics of the GnPs. For example, Liang et al. [3] showed that the tensile modulus of pure PP (1.25 GPa) was 100% improved and reached up to 2.5 GPa with the use of GnPs with diameters smaller than 10 microns and thickness smaller than 5 nm. Chunhui et al. [4] also revealed that flexural strength is inversely proportional to graphite size. The crystallization behavior of the polymer matrix is also influenced when GnPs are present. Therefore, the size of GnPs must be chosen carefully to maximize performance. However, few studies systematically investigate the

influences of a wide range of GnPs sizes, ranging from a few to hundreds of microns, on the various properties of composites. Several physical properties, such as the number of particles per unit volume and surface area, vary with the size of the GnPs and therefore will also have to be considered when discussing various properties of composites.

In the work of the authors, Wang et al. [5] observed that the tensile properties of PP-GnP as the graphene concentration increased, the tensile strength and modulus increased, and the elongation at break decreased. The mechanical properties of the composites decreased at higher temperatures, 165 °C and 170 °C, due to more intense melting. Therefore, the melting temperature of 160°C was chosen as the ideal temperature. Furthermore, the compaction time is also a significant factor in the preparation of PP-GnP. For thermal properties, the single melting temperature analyzed decreased with 0.3% GnP loss of 6°C and 0.5% GnP loss of 4 °C, and the other thermal properties will be analyzed in another work. It was observed that both the use of GnP and the compatibilizer significantly influence the melting temperature of pure PP. The melting temperatures and crystallinity of PP-GnP increased as the amount of graphene increased, indicating that graphene also acts as a nucleating agent. The mechanical properties of the PP-GnP composites also increased with increasing graphene content, which indicates an effective charge transfer between the PP and GnP matrix (graphene). The melting composition can affect the dispersion of the composite PP-GnP and the interfacial interaction between graphene and PP chains, S. Natarajan et al. [6]. The melting temperature can lead to the orientation of molecular chains and graphene to hot stretching. Graphene agglomeration can interfere with the interfacial adhesion between PP composites, worsen the interfacial interaction between Graphene and the PP matrix and induce molecular orientation of the composite.

## Experimental

### *Materials and processes±*

PP homopolymer and copolymer (Braskem), GnP (Pro Cene), and PP-g-MA.

*Extrusion of homopolymer and copolymer PP composites*, with amounts of 0.3% GnP and 0.015% PP-g-MA and 0.5% GnP and 0.015% PP-g-MA in mass. The PP samples – homo and copolymer, the selected graphene and compatibilizer were extruded in a twin-screw extruder in composite grains.

*Injection of test specimens* - The granulated composite material was injected, for the following test specimens: tensile strength, Izod impact, hardness, and melting temperature, according to the ASTM/ISO.

### *Characterization of composites*

The characterized mechanical properties and the corresponding ASTM/ISO standards:

- Tensile strength and elongation (ASTM D638), carried out at CETER-IPEN, São Paulo;
- Impact resistance - IZOD (ASTM D256), carried out at UNIGEL - São José dos Campos/SP;
- Surface hardness (ASTM D785), performed at Thermoblend - Santana de Parnaíba/SP;
- Melting temperature (ISO 11357), carried out at Thermoblend - Santana de Parnaíba/SP.
- Statistically significance: - reference of 10 samples.

## Results and Discussion

The influence of the compatibilizer (PP-g-MA) and graphene (GnP) on the mechanical properties of **homopolymer PP composites** with amounts of 0.3% and 0.5% of GnP +PP-g-MA mass were analyzed.

Table 1, it is shown the results of the characterization of the PP-homopolymer, PP-homopolymer + GnP (0.3% and 0.5%).

Table 1: Results of the characterization of the PP-homopolymer, PP-homopolymer + GnP (0.3% and 0.5%)

MATERIAL	Graphene %	Melt Temp (°C)	Tensile Mpa	Elongation (%)	Hardness Shore D	IZOD			
						w notch (J/m)	WO notch (J/m)	w notch (kJ/m)	WO notch (kJ/m)
PP HOMO PURE	0	180±1.0	34.7±3.6	86.7±3.6	71±1.0	60.4±7.7	NB*	5.3±0.8	NB*
PP HOMO + GRAPHENE	0.3	174±1.0	34.9±1.0	77.1±14.3	71±1.0	86.5±3.9	NB*	7.3±0.4	NB*
PP HOMO + GRAPHENE	0.5	176±1.0	34.4±4.0	73.±8.2	72±1.0	71.9±3.2	NB*	6.3±0.3	NB*

NB\* - no break

The curves of the mechanical properties of the PP-homopolymer, PP-homopolymer + GnP (0.3% and 0.5%) are shown in Figure 1.

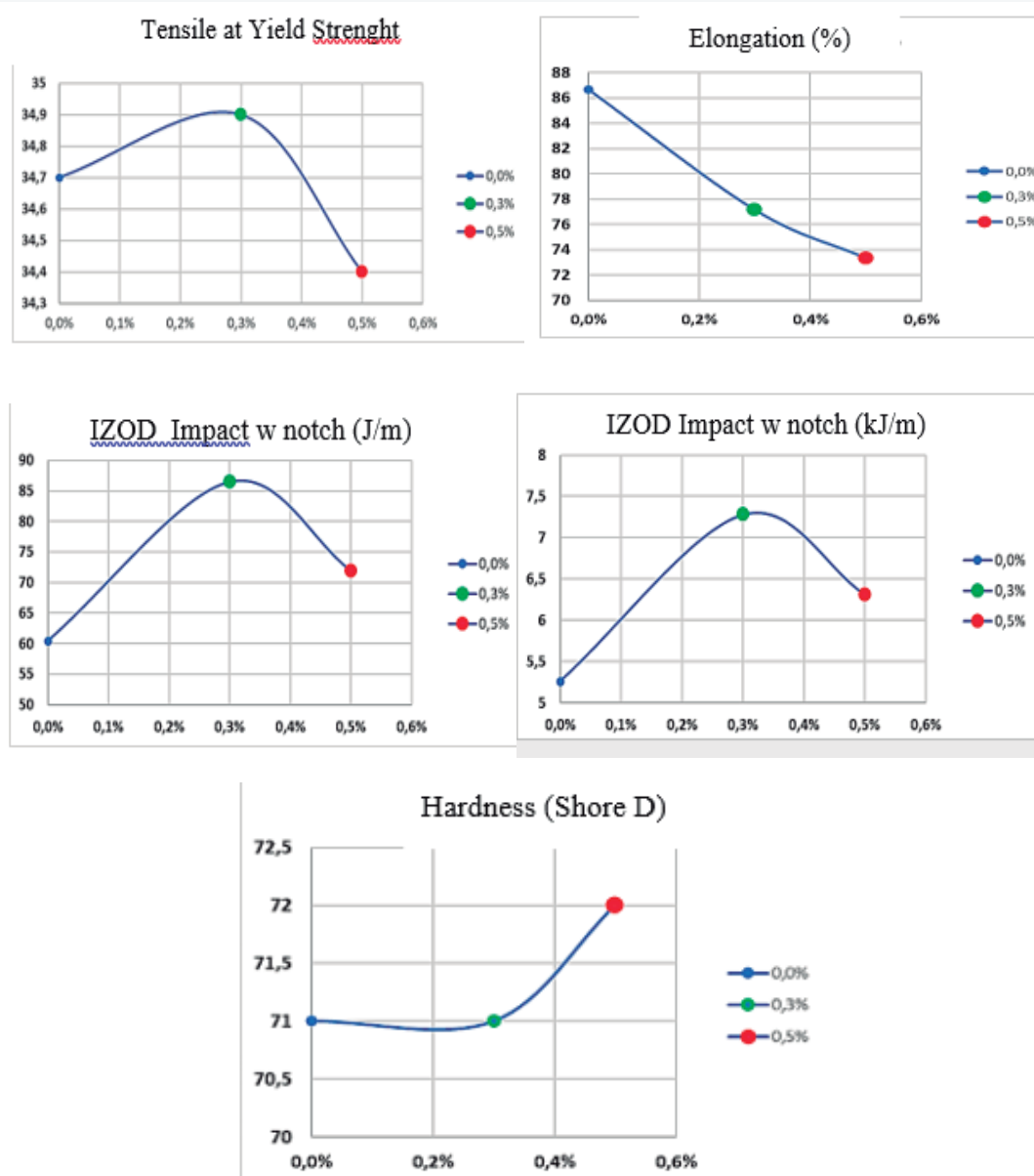


Figure 1: Results of the mechanical properties of the PP-homopolymer, PP-homopolymer + GnP (0.3% and 0.5%)

**Tensile strength**, with the incorporation of 0.3% GnP, increased by 0.2 MPa, and with a 5% GnP decrease of 0.3 MPa. **Elongation** with the incorporation of a 0.3% GnP decrease of 9.5% and with a 5% GnP decrease of 13.3%. **IZOD impact** with 0.3% GnP an increase of 26 J/m and with 0.5% GnP increase of 11 J/m. (NB\*- no break). **Thermal properties**, melting temperature, the only analyzed, the addition of 0.3% GnP decrease of 6 °C (180 °C-174 °C), the addition of 0.5% GnP decrease of 4 °C (180 °C-176 °C), and the other thermal properties are still being evaluated. It was observed that both amounts of graphene and compatibilizer significantly influence the melting temperature compared with homo PP pure.

The influence of the compatibilizer (PP-g-MA) and graphene (GnP) on the mechanical properties of **PP-copolymer composites** with amounts of 0.3% and 0.5% of GnP in mass was analyzed.

Table 2, it is shown the results of the characterization of the PP-copolymer, PP-copolymer + GnP (0.3% and 0.5%).

Table 2: Results of the mechanical properties of the PP-copolymer, PP-copolymer + GnP (0.3% and 0.5%)

MATERIAL	Graphene %	Melt Temp (°C)	Tensile Mpa (+-)	Elongation (%)	Hardness Shore D	IZOD			
						w notch (J/m)	WO notch (J/m)	w notch (kJ/m)	WO notch (kJ/m)
PP COPO PURE	0	168 ±1.0	26 ±0.9	42.1 ±2.2	52	69.3 ±3,2	NB*	6.6 ±0,3	NB*
PP COPO + GRAPHENE	0.3	171 ±1.0	28 ±0.8	53.3 ±2.9	67	176.0 ±5,1	NB*	15.9 ±0.5	NB*
PP COPO + GRAPHENE	0.5	172 ±1.0	28.4 ±0.7	42.9 ±2.9	67	166.7 ±5,3	NB*	14.6 ±0.5	NB*

NB\* - no break

The curves of the mechanical properties of the PP-copolymer, PP-copolymer + GnP (0.3% and 0.5%) are shown in Figure 2.

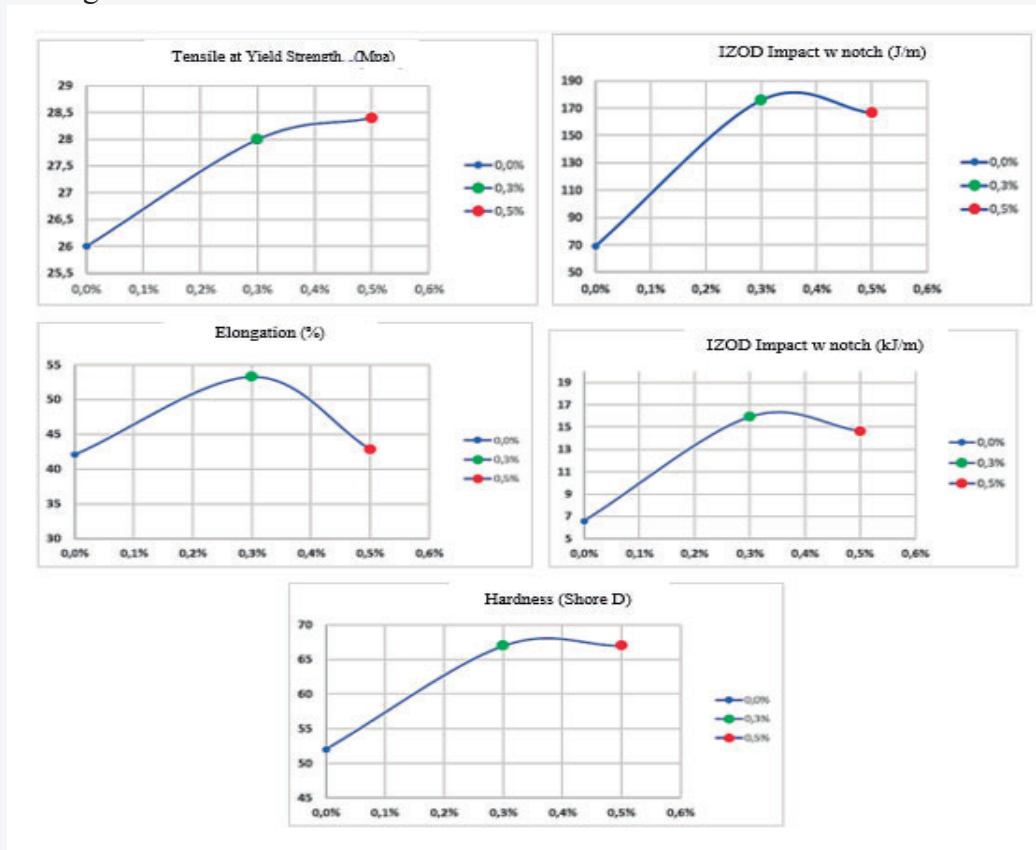


Figure 2: Results of the mechanical properties of the PP-copolymer, PP-copolymer + GnP (0.3% and 0.5%)

The **tensile strength**, incorporation of 0.3% GnP, increased by 2.0 MPa and with a 5% GnP increase of 2.4 MPa. The **resistance to elongation** with the incorporation of a 0.3% GnP increase of 11.2% and with a 5% GnP increase of 0.8%. The **IZOD impact** strength with a 0.3% GnP increase of 106.7 J/m; and with 0.5% GnP increase of 97.4 J/m. There is an ideal amount for addition of up to 0.3% GnP because beyond this amount there will not be a significant increase in the mechanical properties. The slipping effect of the GnP has a great influence on the results and an increase in the cost of the PP composite with GnP with quantities above. For **thermal properties**, melting temperature, GnP with 0.3% increased 3°C (168 °C-171 °C), GnP with 0.5% increased 4 °C (168 °C-172 °C), and the other thermal properties will be analyzed in future work complement. It was observed that both the GnP load and the compatibilizer significantly influence the melting temperature of pure PP copolymer.

## Conclusions

**PP-homopolymer composites** with GnP and PP-g-MA: There is an ideal amount for adding up until 0.3% GnP because beyond this amount there was a drop in the mechanical properties, due to the agglomeration effect and the slipping effect of the GnP and an increase in the cost of the PP composite with GnP with amounts above.

**PP-copolymer composites** with GnP and PP-g-MA: It was observed that both the GnP loading and the compatibilizer have a significant positive influence on the mechanical properties and melting temperature of pure PP copolymer. The PP copolymer has a higher affinity with graphene and compatibilizer due to the elastomeric comonomer ethene, present in PP copolymer, which facilitated the interaction with graphene.

This work can provide an effective strategy to produce PP-GnP composites. Graphene additions with high intrinsic mechanical characteristics can improve the mechanical properties of the polymers and, simultaneously, improve the interfacial properties of PP-GnP.

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