

# Thermal-Resistant Plastic Composites for Industrial Applications: Properties and Processing

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## ABSTRACT

Intumescent thermoplastic composites have found wider applications in recent years thanks to their excellent thermal-resistant performance, low cost and high compatibility in mass production, such as injection molding. A series of intumescent polymer composites containing commercially available polypropylene (PP) and polyvinyl chloride (PVC)-based intumescent masterbatches were compounded respectively, and evaluated for their performances. The plastic composites were analyzed before and after exposure to heat, suggesting that thermal-resistance of the plastics increased with higher intumescent loading, while its mechanical strength dropped. Moldflow simulation and molding trials indicated that intumescent polymer composites could be processed at a lower melting temperature compared to virgin polymer thanks to lower viscosity. This work suggests mechanically strong yet easily moldable intumescent composites enable one to engineer products with desired thermal-resistant performance.

**Keywords:** intumescent compound, thermal-resistance, fire, injection molding, engineering plastics

## 1 INTRODUCTION

Thermal-resistant materials are widely used in various industrial and household products, protecting textiles, plastics, and wood and steel structures against fire [1]. Regarded as one of the most effective thermal-resistant techniques, intumescent systems are able to expand under heat and form a carbonized porous insulation layer, which is able to reduce fire spread and heat transfer [2-4].

Bulk intumescent compound can be formulated by mixing base polymer and intumescent masterbatch. One type of intumescent masterbatch is made of expandable graphite (EG) [5]. EG is a stack of graphites with intercalation of strong acids and other species between carbon layers. Under heating, the intercalated species release gases enabling EG to expand, generating a highly porous structure and acting as insulative layer. Research indicates that EG is able to generate sufficient force to foam even in rigid system, such as phenolic polymers [6, 7]. EG is known to be compounded with thermoplastic materials, such as polyurethane [6], polyethylene (PE) [8], polypropylene (PP) [9] and polyvinyl chloride (PVC) [10], to form injection moldable intumescent

masterbatches. These masterbatch can then be compounded with other base materials for applications in industrial products, flooring, and pipes because of their low cost, good thermal-resistance and easy processability [10].

However the negative effect of graphite on mechanical strength of polymer compounds has been reported [9, 10]. When EG particles are incorporated into polymer matrix, the aggregates create discontinuities in polymer matrix as well as act as local stress concentrations. When the plastic is under mechanical load, small cracks preferentially initiate at stress concentrated points and then propagate through the matrix, eventually leading to ultimate structural failure. Increasing EG fillers thereby decrease the mechanical strength of the composite. Therefore, additives, such as carbon fibers, glassfibers and inorganic fillers, are used as reinforcement to improve the mechanical strength of the intumescent plastics [9-11].

In this paper, PP and PVC-based intumescent thermoplastics were formulated. The intumescent thermoplastics were evaluated for its thermal-resistant performance and mechanical strength. Autodesk Moldflow was employed to simulate the injection molding of intumescent plastics and processing parameters were analyzed. The goal of this study is to optimize the polymer formulation to achieve an intumescent thermoplastic with sufficient thermal-resistance and mechanical strength as well as suitable for industrial injection molding manufacturing.

## 2 EXPERIMENTAL

### 2.1 Polymer Compounding

PP and PVC are selected as the base polymer for intumescent compound due to their wide applications. EG-based PP and PVC intumescent masterbatches were chosen for compounding respectively. Base polymer pellets were first hand-mixed with corresponding intumescent pellets and thereafter the pellet mixtures were compounded, extruded and pelletized via a Desktop SJ25 Extruder (RobotDigg Inc). The compound compositions are listed in Table 1. The resultant intumescent compounds were analyzed via Q500 thermogravimetric analyzer (TGA from TA Instrument). The TGA was performed under nitrogen until 600 °C and then was switched to oxygen up to 1000 °C.

Base polymer [wt%]	Intumescent masterbatch [wt%]
70%	30%
60%	40%
50%	50%
40%	60%
30%	70%

Table 1: Compositions of intumescent plastic compounds.

## 2.2 Flame Test

Injection molded intumescent plaques (125 by 125 by 2 mm) were used in flame test to evaluate thermal-resistant performance. Two thermocouples were attached to the front and back surfaces of the plaque, respectively. At test, flame was aimed directly at the front surface for over 2 minutes to ensure a complete foaming. Temperatures of the front (direct exposure to flame) and back (non-flame-exposure surface) were recorded via thermocouples and plotted with time. After test, the highest foam height of each sample was measured and compared to original plaque thickness. Scanning electron microscope (SEM) of Hitachi S3200N was employed to examine microscopic structures of foamed intumescent materials.

## 2.3 Mechanical Test

The mechanical strength of each intumescent compound was assessed via compression test carried out using Instron 5969 tester. A 20 by 20 by 20 mm cubic was compressed under load at a compression rate of 10 mm/min. The load at which the sample was yielded was recorded.

## 2.4 Moldflow Simulation and Molding Trial

Autodesk Moldflow Insight 2019 was employed to simulate injection molding intumescent compounds under various conditions. The molding parameters were optimized as reference for injection molding. Molding trials were carried out via an Arburg Allrounder 470A. The molding parameters were recommended for industrial manufacturing.

# 3 RESULTS AND DISCUSSION

## 3.1 Intumescent Compound Chemistry

The compound compositions should be well controlled and easy to alter. TGA monitored the weight loss of plastic samples with temperature rise under controlled environment. PP base polymer has 40 wt% fiberglass which will remain even at 1000 °C in oxygen while all EG will be burned off. The total weight loss for PP-based compounds is calculated based on remaining glassfiber content. The inert components in PVC-based intumescent compounds include graphite from EG intumescent and clays in base polymer, which will remain in nitrogen environment. As soon as the purging gas switched to oxygen, all the inert components will be

consumed. Therefore, the composition estimation for PVC compounds is determined by EG weight left in nitrogen gas.

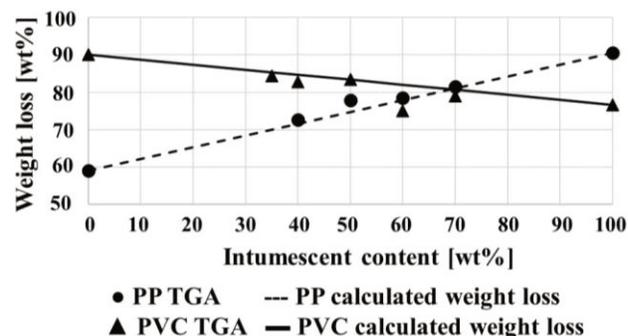


Figure 1: TGA results of PP and PVC-based intumescent compounds compared to theoretical weight loss.

Figure 1 summarizes the TGA measurements. With increase in the intumescent content, the weight loss for PP-based intumescent materials increased correspondingly since less fiberglass was incorporated. On the contrary, more EG graphites are left for PVC-based plastics with higher intumescent content. The theoretical calculations of weight loss are presented as dash and solid lines for PP and PVC, respectively. Noticeably, the trend lines fit the measured data well, indicating that desired compounds are achieved. Moreover, the repeatability of the compounding is also confirmed in such that the intumescent thermoplastics can be reproduced in the same process.

## 3.2 Thermal-Resistant Performance

The thermal-resistant performance of intumescent thermoplastics was evaluated by flame test. Shown in Figure 2, a representative molded intumescent plaque (PP-based compound with 70 wt% intumescent content) was under flame test in IR image, and its temperature profiles of fire-exposed and non-exposed surfaces are plotted.

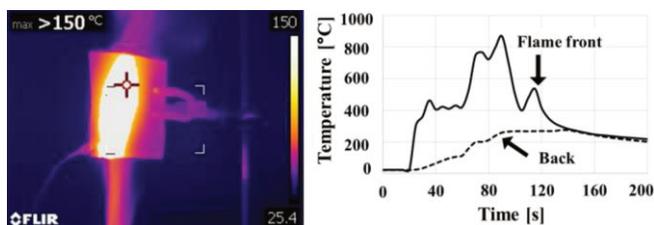


Figure 2: IR image of a molded intumescent plaque under flame test and recorded temperature-time plot of front (fire-exposure) and back (non fire-exposure) surface of a PP intumescent plaque with 70 wt% of intumescent content.

In the flame test, intumescent foaming and charring reactions were observed for all intumescent chemistries. The thermal-resistance of the char is assessed based on temperature difference between the flame and unexposed

surfaces. In typical temperature profiles, the flame temperature was in the range of 800 ~ 1100 °C. The temperature on the unexposed surface which was protected by the expanded char remained around or below 250 °C, resulting in a temperature difference close to 600 °C. We have successfully achieved this 600 °C temperature difference in all intumescent compositions. This thermal-resistant performance is sufficient for our applications.

The excellent thermal-resistant quality of the intumescent thermoplastics originates from expanded, highly porous char structure, as illustrated by the inserted char image in Figure 3. Intuitively, the stronger the char expansion, the more air-pockets trapped in the char, and thus the better the thermal-resistant performance. We use char expansion rate to evaluate char formation, which is a comparison of the highest char height to original plaque thickness. Shown in Figure 3, the char expansion rate vs. intumescent content was measured and plotted. As the intumescent content was raised from 40 wt% to 70 wt%, the char expansion rate increased for both PP and PVC compounds. The expansion rate exhibits a linear increase with the intumescent content before reaching a plateau at content 60 wt%. PVC compounds have a higher expansion rate than PP-base intumescent plastics. It is due to the chemistry of PVC compounds. There are plasticizers added in PVC intumescent masterbatch to improve the processability, and the plasticizers are supposed to reduce viscosity of the polymer melt during heating, and the lower melt viscosity thus promotes char expansion, leading to a higher expansion rate.

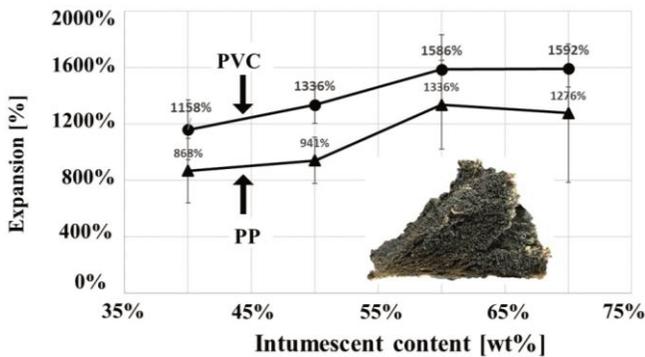


Figure 3: Expansion rate of intumescent compounds related to intumescent content. Inserted image is a foamed PP-based intumescent plaque with 70% intumescent content.

One concern on intumescent performance about inorganic fillers is that fillers, especially glassfibers, will reduce intumescent expansion effect and thus compromise thermal-resistant performance. Report has shown less char expansion in intumescent compounds with higher fiber loading [12] due to glassfiber entanglement making polymer melt more viscous and thus restricting char expansion. Herein the thermal analysis and expansion measurement have shown the measured expansion rates are in the range of those published by the material suppliers, and no evidence indicates that any inorganic fillers or glassfiber in PP cause

reduction in foaming as well as thermal insulation quality. One possible reason is due to the short length and relative low loading of glassfibers in present system.

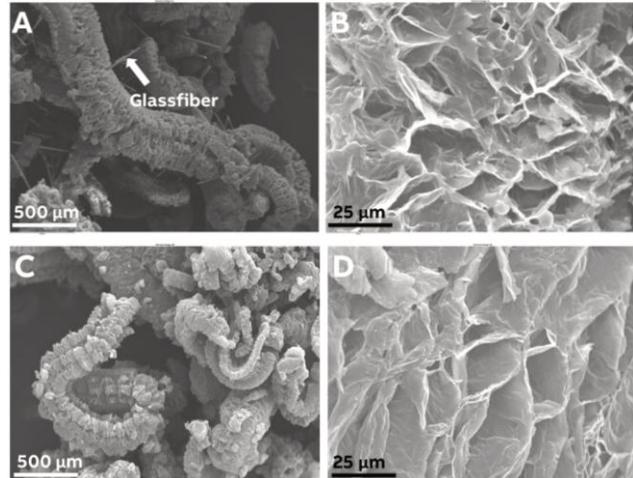


Figure 4: SEM of foamed PP intumescent (A) and (B) and PVC intumescent (C) and (D) at 70% intumescent content.

SEM was employed to examine microstructures of foamed intumescent materials. As presented in Figure 4A, glassfibers were widely distributed in the PP-based compound and were found to penetrate through the pores. Similar to PVC-EG microstructures in Figure 4C and 4D, the highly porous, worm-like EG share the same microstructures of unrestrained char of pure EGs in literatures [13], showing a consequential expansion in the C-direction and dense and closed air pockets. This also suggests that glassfibers have no negative impact on char forming.

### 3.3 Mechanical Strength

The mechanical strength of the intumescent thermoplastics, as shown in Figure 5, illustrates an inverse relationship with intumescent content as reported in literatures [9] [10].

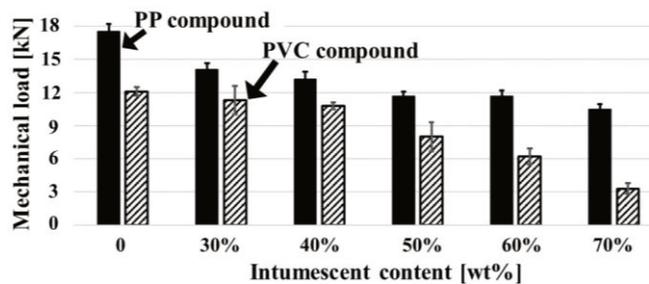


Figure 5: Mechanical load when sample failed at different intumescent contents.

The higher loading of EG destroys the integrity of polymer matrix, reducing plastic mechanical strength. However it is apparent that glassfiber fillers reinforce the

composites, contributing to a higher mechanical strength compared to PVC composites. Also, the plasticizers in PVC increase the plasticity and makes the blend more ductile, causing a reduction in stiffness.

Intumescent content dictates the thermal-resistant as well as mechanical properties of the intumescent composites. The extent of char expansion is enhanced with intumescent content while the material strength is compromised at the same time. Based on thermal and mechanical test, the PP composites with 20 ~ 60 wt% intumescent are selected for our industrial applications.

### 3.4 Moldflow Simulation

20 wt% PP-based intumescent composite was selected for injection molding trial. Moldflow simulation was carried out to analyze the molding property of the material for optimization of molding parameters.

Glassfiber reinforced PP has a melting temperature range of 190 ~ 232 °C while the EG intumescent has an activation temperature of 190 °C. Therefore the intumescent composite has to be processed below 190 °C. Graphite has found to reduce the viscosity of the composite and exhibit shear-thinning property [14]. This shear thinning behavior is critical to the success of injection molding intumescent thermoplastics because it allows a processing temperature under 190 °C if shear rate is properly raised.

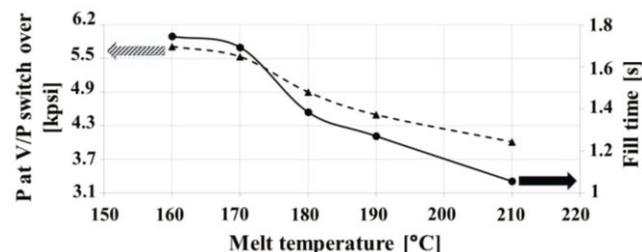


Figure 6: Moldflow simulation of effect of melt temperature on molding pressure and fill time.

In the Moldflow simulation, the viscoelastic data of the PP/EG intumescent compound is used for simulation. The mold temperature was kept at 23 °C. The effect of plastic melt temperature on molding pressure and fill time was evaluated and plotted in Figure 6. It is understandable the pressure and fill time increase as the melt temperature was reduced. Especially, the pressure and fill time rise at a higher rate in the melting temperature range of 170 ~ 180°C, and then they appear to reach a plateau as melt temperature below 170 °C. To reduce the molding pressure and fill time, higher melting temperature is preferred. Considering the upper limit of intumescent activation temperature (190 °C), the barrel temperature is set to 175 °C. Intumescent parts (such as plaque and cubes) were successfully injection molded guided by Moldflow simulation.

## 4 CONCLUSION

In this paper, intumescent thermoplastic composites were successfully compounded by mixing pristine polymer and EG-based intumescent masterbatch. The chemistry of the final intumescent plastics can be precisely controlled and easily modified via pellet compounding process. The EG content will enhance thermal-resistance while reduce mechanical stiffness of the intumescent compounds. PP-based glassfiber reinforced thermoplastic with 20 ~ 60 wt% intumescent content meets both thermal-resistant and mechanical requirement. Moldflow simulation and trial indicates that shear thinning behavior bestowed by EG additive allows intumescent thermoplastics to be injection molded below intumescent activation temperature.

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