PERP Program – Polypropylene Compounding

New Report Alert

December 2005

Nexant's *ChemSystems* Process Evaluation/Research Planning program has published a new report, ***Polypropylene Compounding (04/05S6)***. To view the table of contents or order this report, please click on the link below:
http://www.nexant.com/products/csreports/index.asp?body=http://www.chemsystems.com/reports/show_cat.cfm?catID=2

Background

Polypropylene is an exceedingly versatile polymer, made from a widely available, low cost feedstock in relatively straightforward and inexpensive processes. Polypropylene itself has good mechanical properties, chemical resistance, accepts fillers and selected other additives very well, and is easy to fabricate by a variety of methods. Furthermore, it is quite easy to incorporate small amounts of other copolymers, such as ethylene, to yield polypropylene copolymers with different and commercially desirable properties. Overall, the combination of low cost, ease of fabrication, ability to tailor the resin with co-monomers, and its acceptance of high levels of fillers and other additives make polypropylene a material of choice in many cost-sensitive applications.

However, the levels of fillers and other additives that must be incorporated to achieve the desired properties are difficult or even impossible to incorporate "in-line" in either the polymerization process or in the fabrication step. These fillers generally target specific property improvement, such as stiffness and elastomeric properties, as shown in Figure 1, or to meet service requirements such as flame retardant specifications.

The common materials compounded into polypropylene are mineral fillers (e.g., talc, calcium carbonate or barium sulfate), glass fiber, elastomers such as polyolefin elastomers or EPDM, and high levels of colorants or other additives. The incorporation of fillers and additives by compounding serves to extend the performance envelope of polypropylene to compete with engineering plastics, or against thermoset or thermoplastic elastomers, as shown in Figure 2.

For the purposes of this report, a compound is defined as a mixture of a polypropylene and ingredient(s) in specific proportions to give a defined result or product. The incorporation of small amounts of additives during manufacturing is generally not considered to be compounding. However, the production of a blend of materials (e.g., EPDM rubber and PP to make TPO) is considered to be compounding. Also, the "in-line" production of polypropylene materials containing high levels of additives, most notably fillers, is also considered compounding in this report. For purposes of this report, the market volume numbers will only consider those products made either in-line or in a separate post polymerization step and sold to a third party (e.g., filled materials made in the extruder during fabrication by the end-user are not considered as compounds).

Figure 1 Polypropylene Properties

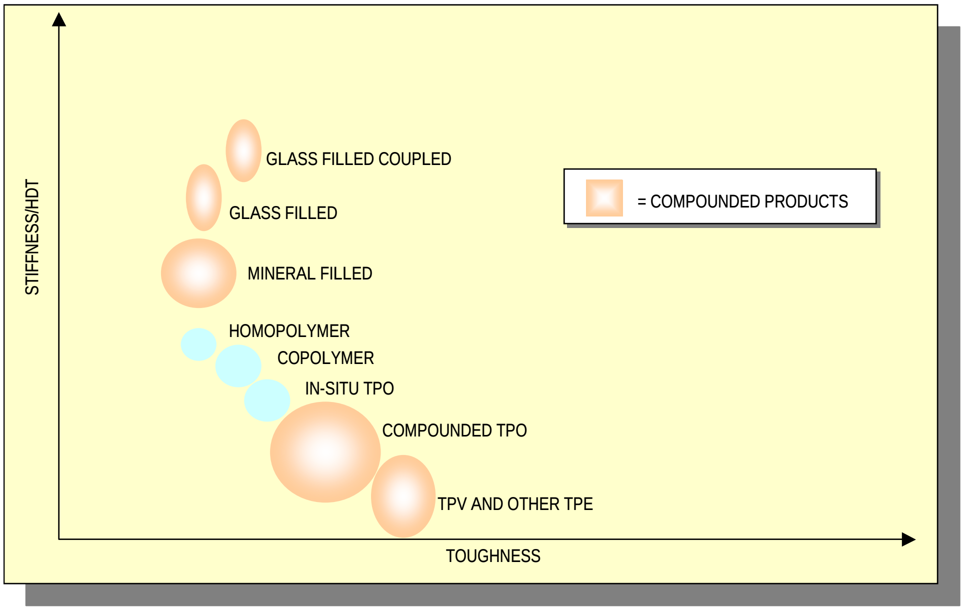

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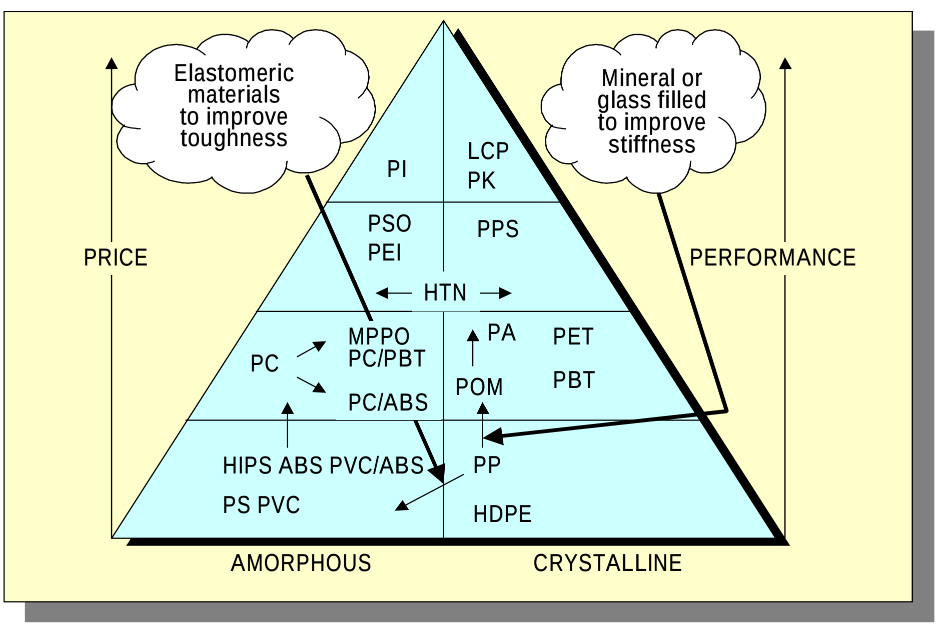
Figure 2 Extending Polypropylenes



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Major Categories of Polypropylene Compounds

Mineral Filled

There are a number of inorganic mineral fillers used in polypropylene. The most common of these fillers are calcium carbonate, talc, and barium sulfate; other mineral fillers used are wollastonite and mica, as illustrated in Table 1. Mineral fillers are generally much less expensive than polypropylene resin itself. Hence, in addition to increasing the stiffness of the resulting compounds, mineral fillers also reduce costs. Mineral fillers generally also provide reinforcement to the polymer matrix as well. Some mineral fillers are surface treated to improve their handling and performance characteristics. Silanes, glycols, and stearates are used commercially to improve dispersibility and processability, as well as to react with impurities.

Table 1 Common Fillers Used in Polypropylene

Filler/Reinforcement	Uses
Alumina trihydrate	Extender; flame retardant; smoke suppressant
Barium sulfate	Used as a filler and white pigment; increases specific gravity, frictional resistance, chemical resistance
Calcium carbonate	Most widely used extender/pigment or filler for plastics
Calcium sulfate	Extender; also enhances physical properties, increases impact, tensile, compressive strength
Carbon black	Filler; used as pigment, antistat agent, or to aid in crosslinking; conductive
Carbon/graphite fibers	Reinforcement; high modulus and strength; low density; low coefficient of expansion; low coefficient of friction; conductive
Ceramic fibers	Reinforcement; very high temperature resistance; expensive
Feldspar and nepheline syenite	Specialty filler; easily wet and dispersed; enables transparency and translucency; weather and chemical resistance
Glass reinforcement (fiber, cloth, etc.)	Largest volume reinforcement; high strength, dimensional stability, heat resistance, chemical resistance
Kaolin	Second – largest volume extender/pigment
Metal fillers, filaments	Used to impart conductivity (thermal and electrical) or magnetic properties or to reduce friction; expensive
Mica	Flake reinforcement; improves dielectric, thermal, mechanical properties; low in cost
Microspheres, hollow	Reduces weight of plastic systems; improves stiffness, impact resistance
Microspheres, solid	Improves flow properties, stress distribution
Organic fillers	Extenders/fillers, like wood flour, nutshell, corncobs, rice, peanut hulls
Silica	Filler/extender/reinforcement
Talc	Extenders/reinforcements/fillers; higher stiffness, tensile strength and resistance to creep
Wollastonite	High loadings possible; can improve strength, lower moisture absorption, elevate heat and dimensional stability, improve electricals

Source: Plastics Compounding Redbook

Typical mineral filler loadings range from 20 to 40 percent by weight of the final compound. Resulting compound stiffness is a direct function of the amount of mineral filler used.

It has also long been known that the smaller the mineral particle size, the better the performance of the resulting compound. It is hypothesized that smaller mineral particle sizes are easier to incorporate into the polymer matrix. However, smaller mineral filler products are more expensive as a result of their increased handling and grinding, and are also lower in bulk density, making them somewhat harder to feed into the extruder.

Thermoplastic Olefinics (TPOs) and Thermoplastic Vulcanizates (TPVs)

TPOs/TPVs have many of the elastomeric properties of vulcanized rubbers, and yet can be molded or extruded using conventional thermoplastic fabrication equipment. They derive their properties from a unique physical network of seemingly incompatible structures, which coexist through chemical bonding. These structures can generically be referred to as soft-block and hard-block components. These materials can exhibit a range of properties because of the different types of hard and soft blocks, ratio of blocks, degree of polymer linearity, crystallinity, and degree of polymerization and cross-linking. Properties can be further changed by co-blending and compounding with vulcanized rubbers, silicone, or other components.

The soft blocks are amorphous, rubber like elastomer components. The hard blocks, with their melting point or glass-transition temperature above room temperature, form domains that prevent plastic deformation and provide tensile strength at normal-use temperature. At melt-processing temperatures, the hard blocks become fluid and the polymer flows under pressure. Upon cooling, the hard blocks again form solidified domains.

Glass Filled

There are several different forms of glass that are used to reinforce polypropylene. The most common form used in polypropylene compounds is short (less than one centimeter) chopped glass fiber. Compounds containing long glass fibers (over 1 centimeter) are also produced. The glass reinforcement imparts strength and stiffness into the resulting compound. It should be noted that a typical short glass fiber compound contains 25 percent glass fiber, 10 percent mineral filler (used to increase stiffness and reduce cost), and the remainder polypropylene. Most glass fibers contain some surface lubricant to improve incorporation into the polymer matrix.

Glass is an inorganic material that is naturally incompatible with polypropylene – the two do not form hydrolytically stable bonds. Hence, a coupling agent is required to improve the bonding forces between the two materials.

Additive Concentrates

Additive concentrates, also called masterbatches, represent a different type of polypropylene compound; they contain a high loading of color or additive(s) and are never used "as is". Rather, the masterbatch is used as a means to incorporate the additive during a subsequent fabrication or compounding step. Loadings can be up to 80 percent additives. Masterbatches are a convenient means of incorporating additives which are otherwise dusty, difficult to feed, or require special handling in their pure form.

Other Polypropylene Compounds

This category includes a wide range of compounds, such as wood composites for outdoor lumber, carbon fiber reinforced polypropylene composites, wire and cable compounds, conductive compounds, compounds for bi-axially oriented polypropylene films, and nanocomposites. All of these types of materials are quite specialized; compounds for bi-axially oriented polypropylene films are probably the largest in volume of these materials. Wood composites are rapidly growing, but the vast majority of these utilize polyethylene as a base resin.

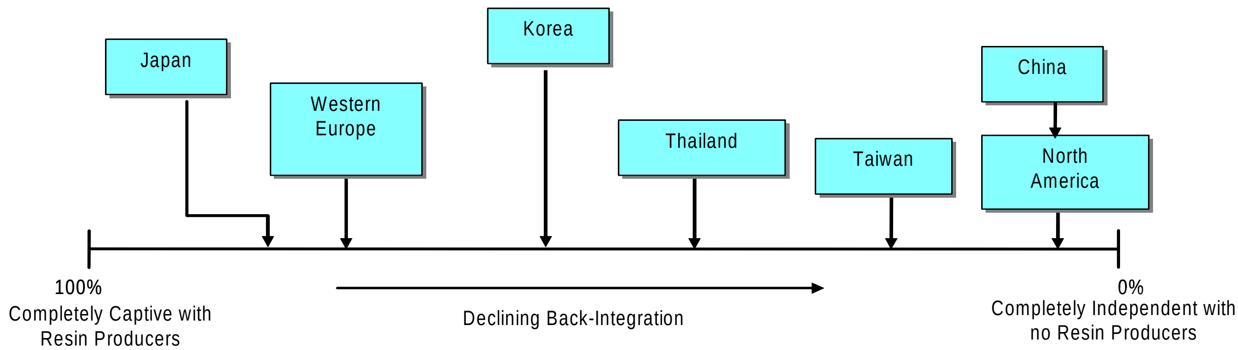
Nanocomposites offer some potential to provide improved barrier properties, stiffness, and flame retardancy at slightly lower mineral loadings. Nanocomposites are filled/reinforced polypropylene compounds which use a filler which has at least one dimension of the dispersed phase in the nanometer range (e.g., less than 100 nm). Montmorillonite clay has been the preferred nano-clay. However, because polypropylene is a low-polarity resin, it has proven extremely challenging to produce a well-dispersed polypropylene nanocomposite.

Compounding Industry Structure

The compounding industry structure is among the most complex of any sector of the chemical industry. This is a direct result of the structural features of the industry, including low investment hurdles, few patent or other technical barriers, and the need to be very responsive on a local level. These features have all served to encourage new entrants into the business in virtually all parts of the world.

Since many polypropylene resins must be either colored or otherwise modified prior to fabrication, the activity of compounding generally began as an obligation of the resin supplier, and indeed remains with the resin producer in many parts of the world (e.g., Japan, Korea, and Western Europe). However, in other parts of the world, new entrepreneurial entities entered the compounding business which became increasingly competitive, particularly for commodity compounds, giving rise to a separate group of companies, occupying this part of the value chain. The current state of the captive versus independent nature of the polypropylene compounding business in various countries is illustrated in Figure 3.

Figure 3 Evolution of Compounding Business
(Illustrative)



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With the continued evolution of the compounding industry, the segmentation and characterization of the marketplace has become increasingly difficult, and is aggravated by the entrepreneurial nature of most participants. One approach to segmentation is on the basis of participant-independent (a firm not affiliated with a resin producer), captive (an affiliated entity of a resin producer), or fabricator with compounding operations.

Although polypropylene resin producers developed compounding technologies and markets, they are slowly yielding ground to others, particularly for small lots.

The Compounding Process

Compounding of polymers began with batch processing of the base polymer. Initially, the industry used equipment designed for rubber, but this was quickly modified to use with thermoplastics. Of this equipment, the Banbury mixer is perhaps the most well known.

The desire to improve productivity yet still retain good mixing characteristics was first addressed with a single screw compounding extruder. This equipment, however, proved to have limitations in the ability to achieve adequate mixing, so alternative approaches were sought.

At this point, compounding technology split into two different directions. One approach was to couple a high intensity continuous mixer to a single screw extruder, the idea being to achieve additive dispersion in the mixing device, and then use the extruder to pump the molten polymer through the desired finishing equipment. This approach has demonstrated that it can achieve high production rates, although this comes at the expense of flexibility in the compounding equipment.

The second approach was to introduce a second screw into the extruder as a means of permitting additional mixing. The twin screw compounding extruder works by passing the polymer back and forth between two rotating screws. This approach provides excellent mixing action and temperature control while retaining the flexibility of the extrusion process.

The modern compounding line is now completely computer controlled, with automatic access to raw materials, through to automatic packaging of the final product. These lines may also be capable of controlling some product change-overs, and storing and feeding back the material produced during change-over.

For many years, the continuous processing equipment had an advantage in terms of lower total cost due to the higher throughput that these lines were capable of achieving. Their higher throughput was a direct result of the fact that mixing was performed in a separate piece of equipment, and both the mixer and the pumping extruder could be designed to maximize throughput. In contrast, the twin screw equipment's advantage lay with its flexibility.

In 1995, a number of companies introduced twin screw compounding lines with higher torque and higher speed (in revolutions per minute or RPMs) as compared to previous models. This new technology has allowed twin screw extruders to greatly increase throughputs, essentially reaching throughputs and economics achieved with continuous processors.

Economics

Economics were developed for three "families" of compounding equipment: conventional twin screw, continuous processor, and high torque twin screw. For each family of equipment, economics were developed for five different sizes. These five sizes span the range of compounding equipment presently used commercially in industry. Capital costs for the high torque lines (extruder, motor, and controls only) are about 10-15 percent higher than the capital cost for the similarly sized conventional twin screw line to reflect changes in the power train and a larger motor. Additional capital is required for additional downstream equipment to handle the higher throughput.

Compounding rates vary widely depending on the polymer used as well as on the additive system. The economics developed in this report are for producing a 35 percent talc filled polypropylene compound. It is assumed that a 15 melt flow homopolymer base resin is used along with a good-quality, good-feeding talc with a bulk density of 15 pounds per cubic foot. There are no colorants; a minimum, though sufficient, additive package is also used.

Operating rates are about 70 percent of the maximum achievable rates typically quoted by equipment manufacturers.

The compounding equipment is assumed to be operated 24 hours per day, five days per week. This is representative of the industry, which uses the weekends for maintenance and to meet periods of high demand. Scrap was assumed to be 1.3 percent, which is representative of industry practice. Utilities consist mainly of power, although a constant $3 per ton was allowed for miscellaneous utility costs such as process water.

Summaries of the economic analyses are given for conventional twin screw compounding equipment, continuous mixer compounding equipment, and high torque twin screw compounding equipment.

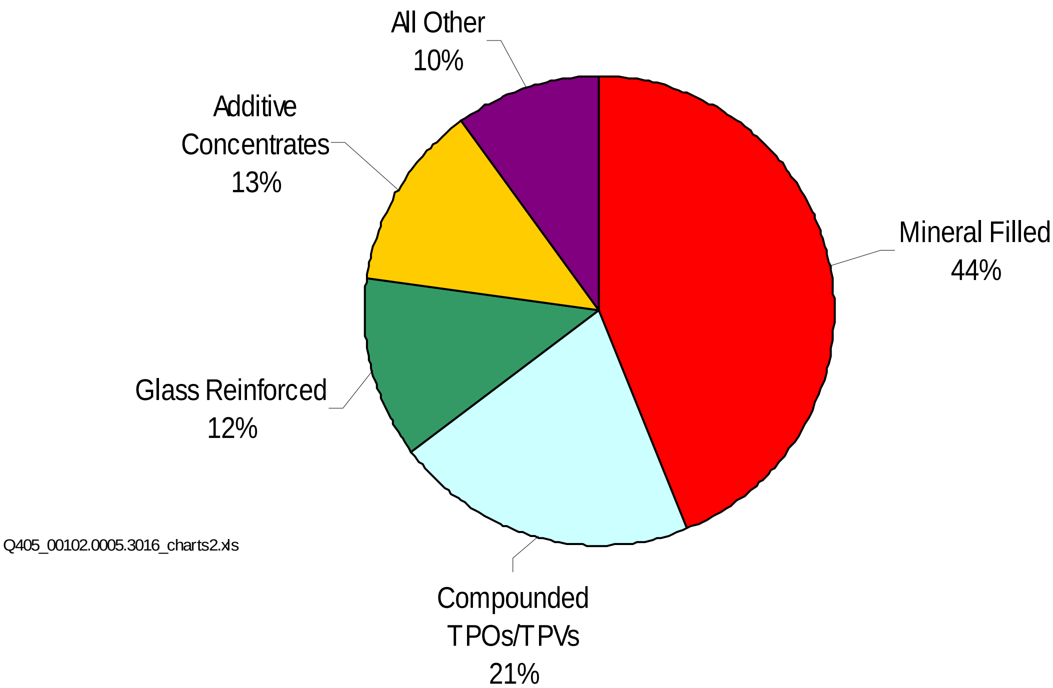
It is evident that compounding costs decrease dramatically with the larger line sizes, particularly in the areas of overhead costs and capital charges. The economics for the smallest line for each type of equipment are not that competitive, and thus these lines are used mainly in producing samples and small production runs. Although the economics favor the largest lines, the volumes associated with a minimum run size are substantial, and are typically achievable only for a few large volume compounded products.

In comparing the economics for the different compounding equipment families, it is apparent that the advances embodied in the high torque machines have closed the gap in the economics between the continuous processor and twin screw compounding technologies. With the economics now very similar, other selling points will come into consideration. In particular, the greater flexibility of the twin screw technology, which permits easier changes in screw configuration and thus can handle a broader range of materials, is an important selling feature.

Supply/Demand

Global demand for polypropylene compounds in 2005 was an estimated 4.5 million metric tons, as shown in Figure 4. Global polypropylene compounds demand growth is forecast to average 4.6 percent per year for 2005-2015.

Figure 4 Global PP Compounds by Type, 2005



Total = 4.5 million metric tons

Detailed supply/demand data are also provided for the United States, Western Europe, and Japan.

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