Thermoplastic compounds: finding the balance between performance and cost

The right combination of polymer, filler and additives can provide a wide variety of performance levels in thermoplastic compounds. However, the relationship between performance and cost remains crucial if the application is ever likely to be successful. Dr. Chris DeArmitt describes an approach that can provide a preliminary assessment of whether a certain plastics compound might be worth further investigation for a particular application requiring certain mechanical properties.

Polymers are very versatile materials offering an excellent combination of processability, properties and price. Plastics have made progress, often at the expense of other materials such as wood and metal. Initially plastics were used where they had lower materials cost than the material they replaced. More recently they are often used because plastics can be moulded into complex parts so that one plastic part can replace multiple metal parts, which avoids the expensive of assembly. Furthermore, plastics have a very attractive life cycle analysis and are some of the most environmentally friendly materials.

There is a wide range of commercial thermoplastics all with unique properties and offering the chance to choose the correct material for a given application. It is generally believed that there will not be any new large tonnage polymers in the future. Therefore efforts are concentrated on expanding the properties of the existing polymers though intelligent use of additives. Fillers have proven very versatile in this regard, providing two distinct advantages - improved performance/cost ratio and access to properties not attainable from unfilled polymers

There are many possibilities for blending fillers and polymers and research continues to yield new discoveries. However, the field is sufficiently well advanced that the behaviour of compounds is rather well understood. Many properties change predictably when filler is added and there are extensive databases listing mechanical, electrical and thermal properties. In practice, it is not unduly difficult to select an acceptable material for a given application. Rather, the challenge is to find the cheapest material that satisfies the requirements. Or, in some industries such as aerospace, and to some extent automotive, it is more important to find a suitable material while minimizing density. Therefore this article will concentrate on how compounds allow for improved performance/cost ratio compared to unfilled plastics and on how fillers impart properties that are otherwise unobtainable.

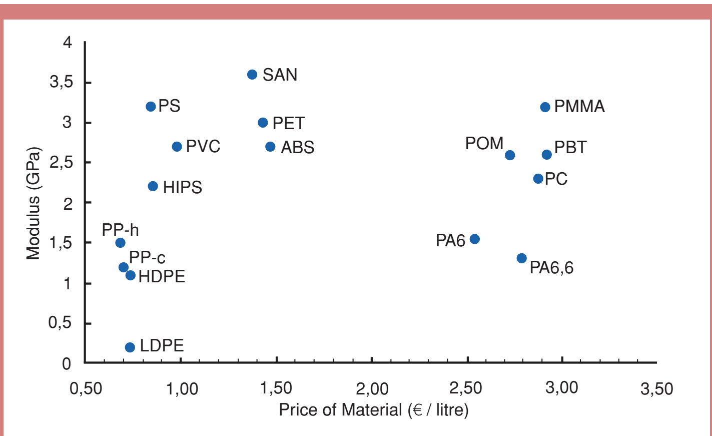

Figure 1: Modulus versus material volume cost for common plastics.

Thermoplastics performance

Fillers are used to alter the properties of plastics, therefore it makes sense to first look briefly at the performance of the unfilled polymers. One can consider many different properties but for this comparison the focus is on the most important mechanical properties - modulus, yield strength, impact resistance and heat distortion temperature (HDT). These properties are depicted as property versus price so that the material with suitable properties and lowest price can be identified (see Figures 1-4). The properties are plotted versus the volume price of the plastic, *i.e.* the price per litre. This is the preferred way to work because that is the way that polymers are normally used, by volume. Even though prices are quoted per unit mass it is more appropriate to use the volume price as it reflects usage.

Figures 1-4 demonstrate why the polyolefins, polyethylene and polypropylene, are dominant in the market. The performance/price ratio is extremely attractive and that is combined with other favourable properties such as chemical resistance and resistance to environmental stress-cracking (ESCR). They are somewhat limited in modulus and especially in HDT.

The styrenic polymers also offer an attractive balance of performance relative to price. They are rather versatile as chemical resistance can be improved by copolymerization with acrylonitrile and impact resistance can be enhanced by adding grafted rubber particles. The higher priced polymers, such as the nylons and PBT, are used where their properties, such as high HDT, are needed.

Each of the polymers is used in the unfilled state for many applications. However, it can be seen from their HDTs that none of the polymers presented would be suitable for high temperature use in the unfilled state. Instead one would have to use a specialized high-temperature polymer such as polysulphone and polyethersulphone.

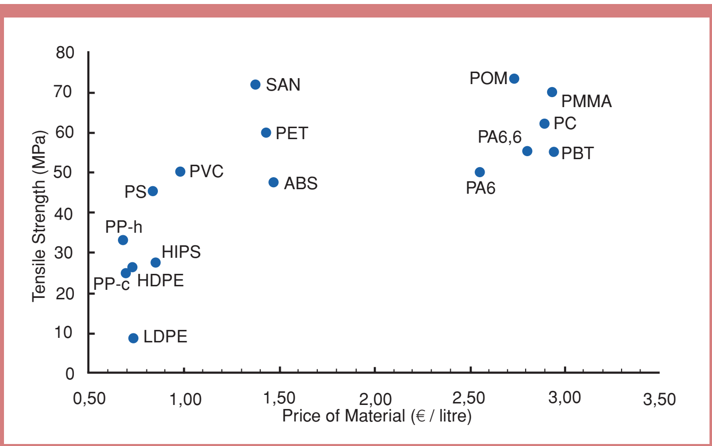

Figure 2:Yield strength versus material volume cost for common plastics.

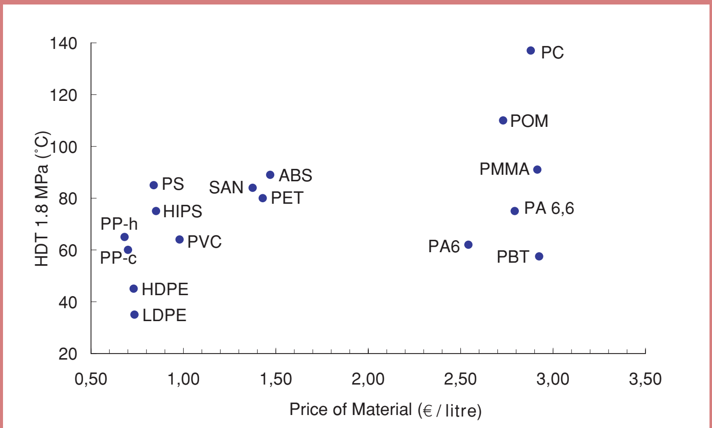

Figure 3: HDT versus material volume cost for common plastics.

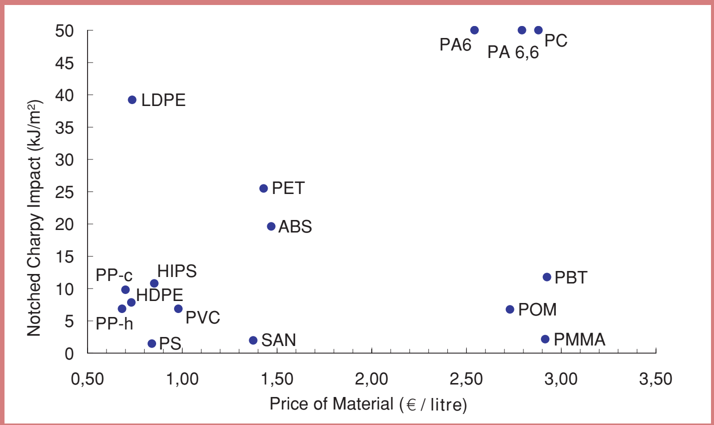

Figure 4: Impact resistance versus material volume cost for common plastics.

Compound performance

By looking at the example of polypropylene homopolymer with various fillers added at a range of concentrations it is possible to get an overview of how different types of fillers influence the properties of polymers. The trends seen for polypropylene apply to other filled thermoplastics.

It is essential to plot properties versus the volume fraction of filler. All properties of a compound depend upon the volume percentage of filler, not on the weight percentage. For example, that is true for processing (viscosity), modulus, strength, heat capacity and electrical/thermal conductivity.

Polypropylene is one of the least expensive polymers and therefore its price is increased by adding most types of filler. Calcium carbonate reduces the material cost while improving many properties (modulus, impact resistance, cooling speed) and gives only a marginal reduction in yield strength. All other fillers increase the volume price of PP and yet they are all commonly used in polypropylene. These fillers are clearly not added to reduce cost and are in fact added because they allow PP to compete with more expensive polymers and at lower cost. The actual type (chemical composition) of the filler is not so important for the mechanical properties of the compound. Instead, it is firstly the particle shape, and secondly the filler surface area, which influence properties. Better properties are observed for fillers that are anisotropic (i.e. platy or

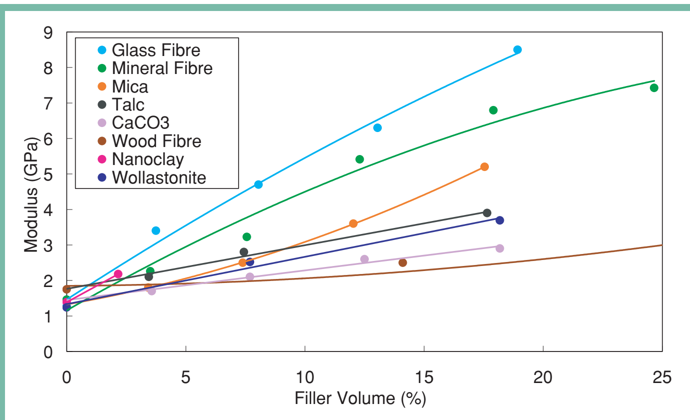

Figure 5: Modulus versus filler content for common fillers in PP homopolymer

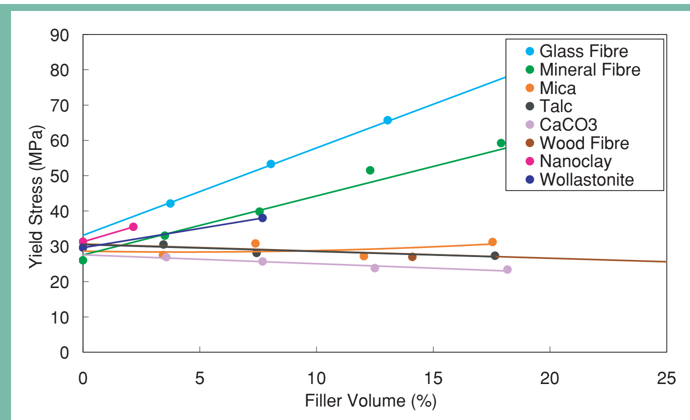

Figure 6: Yield strength versus filler content for common fillers in PP homopolymer

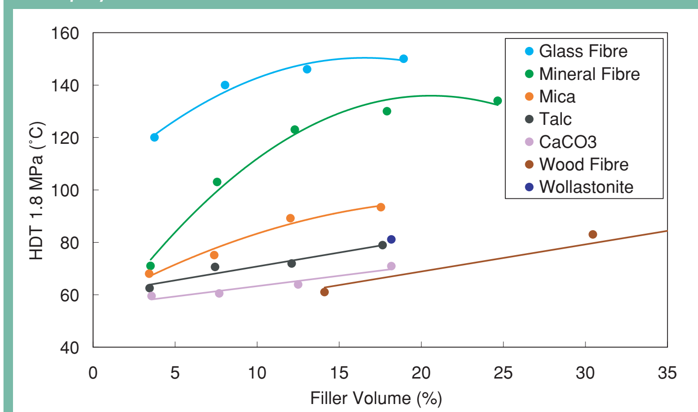

Figure 7: HDT versus filler content for common fillers in PP homopolymer

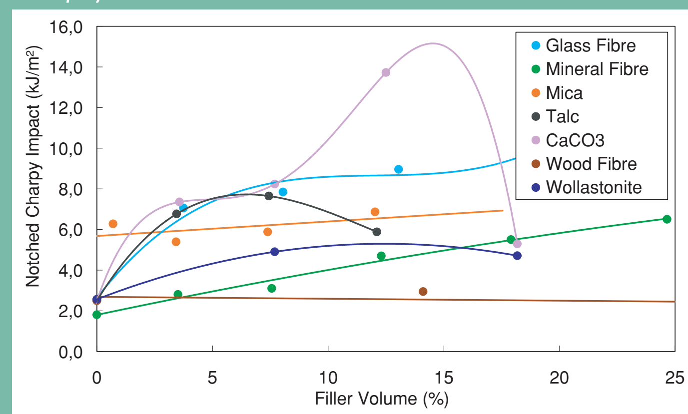

Figure 8: Impact resistance versus filler content for common fillers in PP homopolymer

fibrous) and those with finer particle size. Finer particles give higher surface area of filler and therefore higher interfacial contact area between polymer and filler. This in turn gives greater adhesion leading to improved yield strength. An added advantage of finer particles is that they are normally not so detrimental to impact resistance or gloss.

Consequently it might be thought that very fine, anisotropic particles would provide the ultimate in performance. Indeed, this is the reason for the present frenzy of activity on nanocomposites. By comparing nanocomposites with traditional fillers it is possible to assess whether they are really an attractive proposition.

When comparing nano-clay to glass fibre it can be seen that nano-clay shows similar performance to glass fibre only at a higher materials cost. This means that for structural parts nano-clays are not expected to replace traditional fillers. On the other hand, there are some cases where they are making good progress. One area is in automotive where they can replace talc filled PP to give thinner walled, lower weight parts and still maintain a good surface finish. Another rising area is their use as flame retardant additives especially to promote good char structure.

Anisotropy is good for modulus, yield strength and HDT only in the direction of alignment of the longer axis(es) of the filler. The impact resistance usually suffers when anisotropic fillers are used because the sharp edges act as stress concentrators. Whereas the modulus and yield strength vary linearly with volume percentage of filler, the impact resistance usually drops sharply when even a low amount of large or anisotropic particles are added. Furthermore, anisotropic particles lead to pronounced weld lines, which are weak points in the part. In short, plates and fibres certainly do offer some performance advantages but they cost more and they have disadvantages that should not be overlooked.

High performance fillers

The performance of glass fibres in a range of popular polymers, such as PP, PA and PBT, can also be examined. Glass fibres are more expensive on a volume basis than any of the polymers shown. Therefore it is clear that they are only used when performance levels are needed that are not accessible using less expensive fillers.

Modulus, yield strength and HDT are all improved dramatically using glass fibres. In particular the sharp improvement in HDT means that polymers such as nylon and PBT can be used at much higher temperatures than the unfilled plastics. Usually, impact resistance does not suffer from filling with glass fibres because the fibres help to spread the impact energy over a wider area.

For semi-crystalline polymers such as PE, PP, PA and PBT, adding glass fibre increases the HDT up to a value approaching the melting point of the polymer. The HDT values shown are for an applied force of 1.8 MPa (HDT B)

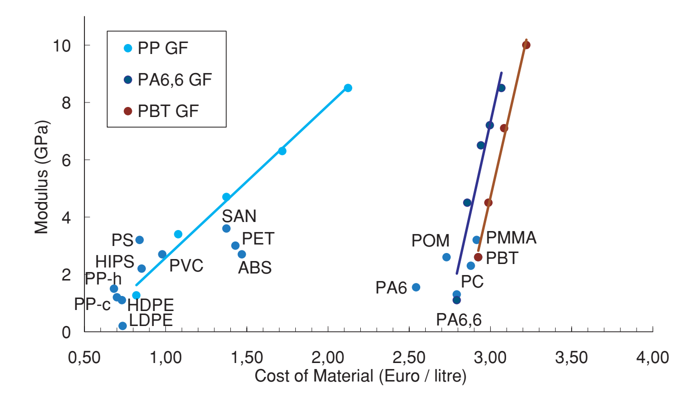

Figure 9: Modulus versus material cost GF-filled plastics and unfilled plastics.

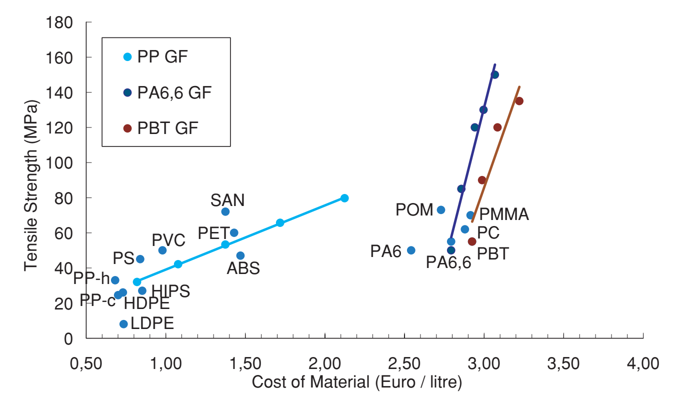

Figure 10: Yield strength versus material cost GF-filled plastics and unfilled plastics.

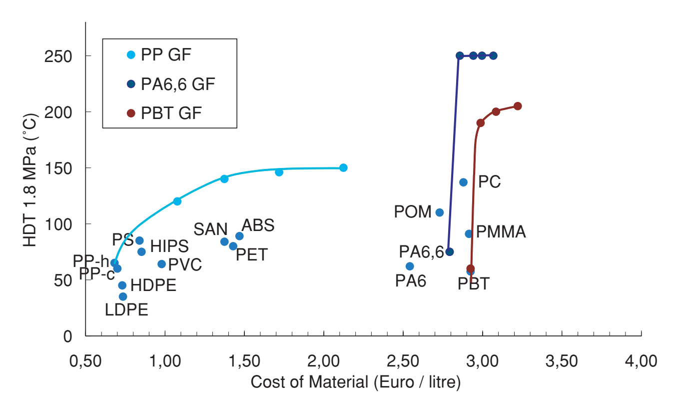

Figure 11: HDT versus material cost GF-filled plastics and unfilled plastics.

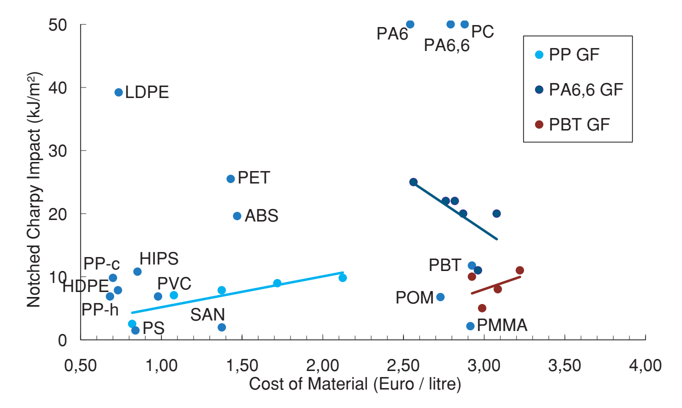

Figure 12: Impact resistance versus material cost GF-filled plastics and unfilled plastics.

corresponding to the part under load. It is important to compare like with like as there are also HDT values for a force of 0.46 MPa (HDT A) and these can be significantly higher due to the low applied stress. Vicat B values are often similar to the HDT B although strictly speaking Vicat is only a surface measurement whereas HDT measures bulk behaviour. For amorphous polymers, glass fibres are also effective at raising modulus and yield strength but fillers are not as effective at raising HDT. For amorphous polymers, adding glass fibres will increase the HDT up to a value approaching the glass transition temperature (T_g) of the polymer.

Conclusions

Plastics play an irreplaceable role in everyday life due to versatility and a competitive price. Fillers are able to enhance plastics in two ways. Firstly by improving their performance/cost ratio and secondly by imparting properties not attainable using unfilled plastics.

Any discussion of performance is meaningless without considering cost. It is not particularly difficult to find a material that will meet a given set of requirements. The key to competitiveness is to find the least expensive material that will suffice. As the possible combinations of filler, polymer and additives are endless, it is helpful to create a method for the systematic comparison of materials graphically. Using openly available data, it is possible to compare a multitude of materials in terms of performance/cost. Using such a tool, it becomes possible to find the correct material and indeed to identify fruitful areas for innovation. For example, filler mixtures can provide new materials with an attractive performance/cost ratio. Similarly, when evaluating a coupling agent or dispersant such graphs can be used to gauge accurately whether the additives are worth the extra expense.

Polymers and in particular filled polymers have a bright future. As we learn more about their behaviour we can then create new materials that are able to satisfy the demands for good, inexpensive materials that provide for a sustainable environment.

Information sources:

Plastics compounds data - Matweb (www.matweb.com) and CAMPUS database (www.campusplastic.com)
Prices - www.plasticstechnology.com/dp/pt/resins.cfm

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