Impact Modification

Plastics applications always involve compromise --- there is always a tradeoff of one property for another. One property that most applications desire, however, is good impact strength. After all, no one wants the part to break when it's dropped or otherwise mishandled in an expected or foreseeable way. The problem is that the material with high strength, or high rigidity, or chemical resistance, mandated by the application, often only provides limited impact resistance. So, somehow the polymer needs to be modified to enhance its impact resistance without seriously inhibiting other key desirable properties.

We've talked about T_g before: if the glass transition temperature can be lowered, the impact strength can be enhanced. Adding a compatible plasticizer to the compound will lower the T_g of the material. Copolymerizing with a lower T_g material can also improve impact resistance. While impact resistance is increased, however, the property enhancement comes at the expense of decreased modulus (stiffness) and yield strength.

Adding a filler can, in many cases, moderately increase the impact strength. A well-dispersed filler like calcium carbonate, talc, or other similar material can introduce sites for flaw initiation during impact. By initiating defect formation at numerous locations simultaneously, the part is capable of absorbing more energy without catastrophic failure of the part--- although it doesn't mean that it will be capable of sustaining a second or third similar event. Adding filler to increase impact resistance usually offers the additional advantage of enhanced economics --- expensive plastic is substituted by an inexpensive filler. The compromise is that adding filler to a tough material, tends to make the material harder, stiffer, and less capable of extension, i.e., more brittle. Furthermore, if you add too little filler to the compound, you get these negative effects with no significant impact enhancement; while if you add too much filler, you get all of the negative effects plus reduced impact strength.

A common way to increase impact resistance is to add a reinforcement, like glass fiber, to the material. In many regards, particulate fillers are truly reinforcements because they are generally not added to the compound to purely "cheapen" the material but to enhance properties. The general distinction between a filler and a reinforcement is a function of its aspect ratio --- the ratio of its length to thickness or diameter. A material with an aspect ratio of 3:1 or less may be considered a particulate filler, while one with a higher aspect ratio offers some directionality to the filler and behaves more like a fibrous reinforcement. These high-aspect-ratio materials, i.e., fiberglass, cellulose, wollastonite, mica, etc. are considered reinforcements.

Reinforcements are generally high modulus materials --- they are usually stiffer than the polymer they are reinforcing. That means, for any small amount of deformation or stretch, the reinforcement will carry a higher proportion of the load, effectively lessening the load carried by the polymer, which allows the composite system to absorb more energy or work during deformation. This mechanism, however, requires good adhesion or "coupling" of the reinforcement to the matrix; therein the requirement of sizing or coupling agents for the reinforcements to secure the reinforcement to the polymer matrix.

Another common way to improve impact strength is to add another polymer to the system, one with a low glass transition temperature, that can absorb and dissipate some of the energy. Typically, one will add an elastomer to a rigid polymer to improve its impact resistance. However, like a plasticizer, the more of the soft phase added to the rigid polymer, the more the tensile strength and modulus are reduced --- usually an undesirable offset. Furthermore, impact strength enhancement is affected by the morphology --- the size and shape of the elastomeric phase. Very small spherical discrete elastomeric particles offer almost no significant property enhancement, yet at a particular size, which is specific to each matrix resin, significant impact property improvement occurs with little effect on tensile strength and modulus. With the same rubber content, further size increase in the elastomeric domain, however, results in significant softening of the composite system with a reduction in impact strength due to the fewer number of rubber particles for that amount of elastomer.

Not only must the proper size and shape of the elastomeric domain be attained, but it must be <u>maintained</u>. It's not enough to produce a material with the right morphology, but it has to ultimately maintain that structure and be processed into a part. It is the molded part which must have the proper morphology, and morphology is affected by the shearing action involved in processing. The elastomeric and rigid phases are generally very different materials and are, therefore, incompatible from the point of view that they don't want to mix --- they separate into different phases. Shearing of the melt during processing will establish the ultimate morphology of the different phases. Under high laminar shear, the discrete spherical shapes may coalesce and form layers separated by layers of rigid material. Under relatively low shear, the discrete elastomeric particles can agglomerate and form larger spheres --- effectively undoing the critical morphology control introduced into the material at manufacture. At high shear that can occur at gates or impingements, the controlled particle morphology can be broken down to very small phases which provide little impact enhancement.

What material manufacturers do to control morphology of the discrete elastomeric phase is to start with elastomeric particles of a controlled size, shape and distribution. The rubbery phase is slightly crosslinked to maintain the particulate shape and limit agglomeration during processing. Secondly, the elastomeric particles are "soaked" in the polymerization medium (monomers, or monomer and solvent), which causes the rubber particles to absorb the polymerization mix and swell. When polymerization occurs, polymer is formed inside the elastomeric phase as well as on the outside. After polymerization, the correct-size particle is formed, but because of the hard resin inclusions, less rubber is used for impact modification, thereby reducing potential losses

of rigidity while increasing impact strength. As an added benefit, some of the polymer attaches itself to the rubber phase, and grows on the surface. The graft copolymer formed on the surface acts as an emulsifier to keep the particles from coalescing. In addition, the graft copolymer behaves as a compatibilizer to enhance adhesion to the rigid matrix.

Impact modification can be achieved by simple additions or modification of the compounds --- but not without the concurrent tradeoff in other properties. However, impact modification can be achieved with only moderate compromise in other properties --- but only through the sound application of material and processing technology and knowledge of how these technologies interact on the mechanical behavior of the polymeric system.

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