

Abstract

Overmolding Thermoplastic Elastomers (TPEs) has come of age. From the traditional usage of TPEs in rubber replacement¹, emerging consumer market trends have driven the overmolding concept to commercial reality. Consumer market demand and trends for enhanced ergonomic feel and touch, grippability, aesthetics, cushioning against impact, vibration isolation and insulation are escalating. Designers for consumer products are setting the pace for material developers to provide solutions that offer a combination of aesthetically pleasing look and feel along with demanding end-use functional performance.

This paper covers general aspects of overmolding technology and TPEs as a class of materials that offer engineered solutions for this evergreen trend. Rigid substrates include polypropylene (PP), polyethylene (PE), amorphous polar plastics such as polycarbonate (PC), polymethylmethacrylate (PMMA), polystyrene (PS), high impact polystyrene (HIPS), polyphenylene oxide (PPO), glycol modified polyethylene terephthalate (PETG), Acrylonitrile Butadiene Styrene (ABS), semi-crystalline polar plastics such as polyester (PET, PBT) and Polyamide (Nylon 6, Nylon 66). Novel material technology of blending and compatibilization have made it possible to offer products to meet the overmolding needs onto these various substrates.

Many factors are very important for overmolding TPEs onto rigid substrates. The selection of the type of TPE in combination of the rigid substrate is the first and foremost. Equally important are overmolding process (i.e. insert or 2K Molding), machine type, process conditions, material preparation, part design and mold design. A combination of novel material technology, part and tool design as well as innovations in overmolding technology will continue to fuel the imagination of the designer community to meet the ever-demanding needs in ergonomics, aesthetics and value addition in the consumer market.

Introduction

Two-component injection molding of thermoplastic materials has been practiced since 80's by the automotive industry. However, most of the combinations were limited to hard thermoplastics. In the last decade, applications have emerged which demand combining hard and soft thermoplastic materials. Today there is phenomenal interest in overmolding TPEs onto rigid substrates, particularly in the consumer product arena, in applications requiring a soft touch. Overmolded TPEs can provide functionality such as providing a safe strong grip in wet environments, waterproofing gaskets and seals, molded-in "bumpers" to provide impact resistance to prevent premature breakage, and vibration damping. In applications such as power tools, hand-held appliances, hard and soft thermoplastic material combinations are used to provide functional properties such as vibration dampening, insulation from heat & electricity and wet grip. This is achieved by molding a soft skin of thermoplastic elastomer over a hard engineering plastic.

With an increasing awareness of ergonomics and the rise in joint overuse injuries, consumers are savvy to products that will fit their bodies better and provide cushioning and impact resistance. Hard and soft combinations are also used for ergonomic considerations, for example hand-held electronics such as cell phones have used hard and soft combinations to give a soft touch feel to their product and for product differentiation. Beyond soft touch, many consumers prefer a "warm" soft touch feel over a hard plastic feel. And, a rubbery look and feel is often perceived to be of higher value.

Moldability

In the last two decades faster output has forced the industry to look into other ways of combining materials. Two-component injection molding has gained popularity because of its faster process time and versatility of combining a wide variety of materials. The two-component injection molding, also referred to as two-

shot molding, consists of a machine with two independent injection units, each of which shoots a different material in series. The first material is injected through the primary runner system while the mold volume to be occupied by the second material is shut off from the primary runner system. The mold is then opened and the core plate is rotated and the second material is injected from the secondary runner system.

A more economical approach is insert molding. It has a lower output than two-shot molding. In insert molding, a pre-molded rigid plastic substrate or metal part is inserted into the cavity via robotics or an operator. The second (over-mold) material is either injected onto one side of the insert or sometimes completely surrounds the insert. Insert molding can be done using conventional injection molding equipment.

Engineering Plastics

A wide variety of engineering plastics are used to design molded products. The selection of the plastics is made based on the functional performance needed in the end-use application along with the fabrication process.

The engineering plastics can be classified into two broad categories- semi-crystalline and amorphous plastics. The Semi-crystalline, because of their crystallinity, have good resistance to chemicals. The crystalline melting temperature determines the service temperature of the product. Higher the melting temperature, higher is the service temperature. Some of the semi-crystalline polymers include Polyamide, Polypropylene, Polyethylene, Polyurethane, Acetal and Copolyesters. Some of the negatives of having crystallinity are that it makes their processing more challenging. Depending on the percentage crystallinity and kinetics, the process window could be limited by shrinkage, flashing and molded-in-stresses.

Some of the commercially available amorphous plastics are Polystyrene, Polycarbonate, and Acrylics. Some commercial amorphous polymers are also blends of two or more different polymers such as blends of Polyphenylene oxide/Polystyrene, Acrylonitrile Butadiene Styrene. The lack of crystalline phase transition helps with processing, however, it also reduces the chemical and heat resistance in amorphous plastics.

The selection of engineering plastics for an application is based on the required properties such as chemical resistance, service temperature, processability, shrinkage etc. For example, if rigidity and chemical resistance is required for a hand held power tool, Polyamide is the material of choice. Similarly if clarity and memory is required, polycarbonate is preferred for the substrate. Overmold elastomer is usually a thin skin molded on top of the engineering substrate. So if certain performance requirements such as chemical resistance, clarity and heat resistances are required for the substrate, similar performance is expected for the elastomer as well.

Elastomers

Thermoplastic Elastomers are based on hard and soft segments. These segments can either be built in the molecular architecture or created in the morphology. The hard segment determines the chemical and heat resistance of the product whereas the soft segment influences the elasticity and softness in the product.

Following are the commercially available thermoplastic elastomers that can be used for overmolding:

- Styrenic block copolymers
- Olefinic Copolymers
- Thermoplastic Vulcanizates
- Thermoplastic Urethanes
- Copolyesters, and
- Copolyamides

Each of these chemistries offer unique properties and performances related to the overmolding applications. Some are more economical than the others are. Some have better chemical resistance and heat resistance

and some have better processing compared to others. All of them are used in the overmolding arena either separately or blended with different chemistries.

The Styrenics and Olefinics elastomers are one of the most widely available chemistries in the market. These are based on hydrocarbons and are similar in polarity compared to PP and PE but don't have significant polarity built in the molecule compared other engineering plastics. Because of this low polarity they do not tend to absorb moisture during their storage and during processing which makes them easy to handle and manufacture. Also because of low polarity they are less prone to staining, which is a very important characteristic in overmolding applications.

Styrenics morphology is fully amorphous and Olefinics have limited crystallinity. This results in poor chemical resistance for ASTM 903 oil and other non-polar chemicals. This is a limitation in overmolding applications that require chemical resistance. Also, because of lower transition temperatures of the hard segment, these elastomers have lower service temperatures.

The polar elastomers consist of Urethanes, Copolyesters and Copolyamides. These elastomers are close in polarity (Table 1) compared to engineering plastics. Because of similar polarity the elastomer and engineering plastics are very compatible with each other. If these elastomers are chosen for overmolding they result in a favorable level of adhesion with the substrate.

Urethanes, Copolyesters and Copolyamides also have good resistance to chemicals, esp. ASTM 903 oil and other non-polar chemicals. Also because of the high transition temperature of the hard plastics, the service temperature can be higher. The drawback of having polarity is that these chemistries tend to absorb moisture during storage and processing. This brings the need to dry them before processing, and cause other limitations in manufacturability.

Overmold Requirements

Adhesion

For the TPE to function in the application, the first and foremost requirement is to have good adhesion to the substrate and simultaneously meet other functional properties. Adhesion is required not only for longevity of the product, but also as tamper evidence.

Adhesion between the TPE and the substrate is strongly dependent on the surface energy of the two materials. Table 1 shows the surface energy of most commonly used elastomers and substrates. As it can be seen, TPU, COPE & COPA are close in surface energy to PA, PC and ABS type of substrates. This makes them the material of choice for adhesion requirements.

Ergonomics

Since the elastomer forms the outer surface in an overmold part there are certain ergonomic requirements for the elastomer to meet. Softness (lower durometer) is required to give cushioning so the consumer doesn't feel the vibrations or impact during the use of the product. Numerous field-testing has indicated that the consumer perceives hardness in the range of 35 Shore A to 70 Shore A to be ideal. Figure 2 shows the hardness range of all the elastomers chemistries. It is clear that only styrenics and TPV's can provide the required hardness range for overmolding.

Colorability is also an important attribute for overmolding. The driving force behind the popularity of TPEs is point-of-purchase sales. Today's consumer faces a boggling number of choices at a retail store, and manufacturers want to set their products apart. The elastomer is required to have good colorability to aid in product differentiation. S-TPE and Olefinics being clear to translucent provide a greater range of

colorability options to the designers. TPU's can also be clear, but are very sensitive to UV, which limits colorability options. TPV and COPE not being translucent also have some limitations on colorability.

Other ergonomic considerations include low coefficient of friction, scratch and mar resistance, UV resistance and resistance to dirt and skin oil. Table 2 lists the characteristics of each of these chemistries for the above mentioned properties. It can be seen that certain elastomers fare well in specific characteristics than others. But for certain characteristics such as low-COF none of the elastomer chemistries work well by itself, and need further modification.

Performance Characteristics

Performance characteristics such as chemical and heat resistance are also required depending on the applications. Chemical exposure of elastomers results in a wide array of changes to the physical properties. Depending on the effect on elastomer- absorption or extraction, changes in hardness, elasticity, tensile properties and other performance properties can be seen. However, since overmolds are supported by the hard substrate, some of the changes are not relevant to performance. So if the tensile properties change with chemical exposure, there is no effect on overmold performance since it is not stretched during its use. The most significant characteristics are change in hardness (softness) which can change the feel of the product, and change in weight, which can also effect the feel of the product.

Effect of heat on dimensional stability and surface tack also needs to be taken into consideration. If the overmold products can deform at higher temperature, they can cause problems in shipping during summer months when the temperature can reach above normal temperatures.

If the application is for outdoor use, the product would also need good UV resistance. Hydrogenated styrenics, Olefinics and TPV's fare very well with UV exposure, whereas COPE, TPU and COPA are not as good in UV resistance.

Processability

Most overmolding applications involve molding a thin skin of elastomer over a rigid substrate. Since the elastomer has to flow in molds requiring longer flow lengths it needs to have high flow characteristics. Spiral flow is a good measure of a materials flow in molds with long flow lengths. Table 4 lists the spiral flow characteristics of some of the conventional elastomers used in the industry.

Apart from long flow length the materials also need to have faster set up. Overmolds can be developed with slower setting elastomers, which in return increases the wettability and improves adhesion to the substrate. This phenomenon is especially seen with softer TPU (65 to 75 Shore A) overmold products used with substrates such as ABS and PC. The TPU provides exceptional adhesion. However, because of its slow setting rate it increases the cycle time in manufacturing.

Because of the inherent requirement to have good adhesion to the substrates, overmold products can have problems with mold sticking. These products usually have very low melt viscosity, which helps wetting the substrate. This helps with adhesion but increases mold wetting and if the mold is not designed will it can result in flashing. Mold sticking will result in problems with de-molding as well and can also cause the substrate to deform because of un-due stresses put on the part.

Product Technologies

Based on the requirements for over-molding there is no single chemistry that fits the needs of the market. Some give good adhesion to substrate and others are superior in manufacturability and ergonomics. The only way to meet the needs of the market is by compounding TPE materials that bridge the gap of the

above mentioned chemistries. Blending materials can bring synergy in material properties and offer functional solutions to the market.

Table 3 shows the physical properties of the products that were developed by GLS for overmolding on to PC, ABS, PC/ABS Blends, PETG, and PA. . These substrates are widely used and represent most of the overmold applications in the market. We have used our technical understanding of polymer compatibilization and developed products that combine the positives of different elastomers and come up with a technology that can meet almost all the requirements of the overmolding market.

The bond strength between the TPE and the engineering plastic is measured by performing a “90° Peel Test”. We have modified the ASTM D903 method for plastics to evaluate the adhesion of soft TPE onto rigid thermoplastic. Table 4 shows the adhesion strength of developed products on PC, ABS and PA. Based on adhesion strength required by the consumer, we have categorized an adhesion value higher than 13 pli to be acceptable for adhesion. As it can be seen from the data, these products fair very well in terms of adhesion to the substrate.

Table 5 gives the adhesion performance of other commercially available TPE products for overmolding on various substrates. Comparing data from Table 4 & 5 it can be seen that GLS TPE product perform at par or better compared to all other commercially available TPE materials in terms of adhesion performance.

Figure 2 & 3 shows the performance of these products when exposed to ASTM 903 oil along with typical S-TPE, TPV and a TPU product used in the industry. As mentioned earlier, hardness and weight changes are the most relevant property changes for overmold products. Compared to the conventional elastomers, these overmolds perform fairly well in chemical resistance.

Table 6 shows the spiral flow data on these products along with the industry typical elastomers. Higher spiral flow indicates high flow characteristics. This shows that these products can do very well in thin wall molding, which is typical to an overmold application.

In terms of ergonomics all these products feel very rubbery and warm to the touch. This is a key characteristic as indicated earlier. All of them show good resistance to scratch and mar and show favorable results in other ergonomic considerations.

Conclusions

The future of TPEs for overmolding applications looks bright indeed; in fact, almost limitless. TPEs allow designers to add improved aesthetics, better feel, increased performance, and consumer appeal to their products for a marketable, differentiable advantage. The variety of hard-soft combinations is expanding rapidly to meet customer trends, and going forward, the industry and customers can expect to see new and innovative solutions that add value and performance to new and existing products. The market trend will continue to drive technological leap in equipment, design and product chemistry.

No single elastomer technology meets all the market requirements. Compounding is the only possible way to develop products that can meet all the requirements. Compounding plays a key role in developing products that meet the requirements.

Table 1: Surface energy of different polymer resins.

Plastic Resin	TPE	Surface Energy (mN/m)
PP		29
	TPV (Sarlinc 3160)	32
	Olefinic (Engage 8400)	34
	S-TPE (G2705)	37
PS		38
PMMA		40
	COPE	41
PC		42
ABS		43
	TPU	43
	COPA	43
PA 66		46

Figure 1: Hardness comparison of TPE technologies.

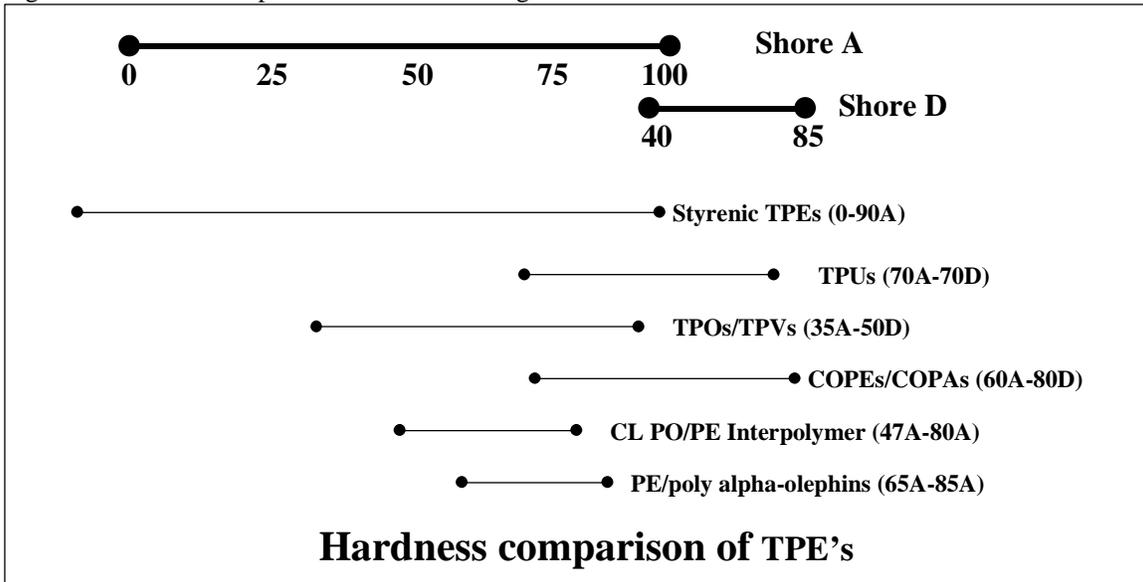


Table 2: Performance of TPE chemistries in ergonomic factors considered in overmolding applications.

	Olefinic	TPV	S-TPE	TPU	COPE	COPA
Low COF	0	+	0	0	0	+
Scratch & Mar	0	+	+	+++	+++	+++
Abrasion	+	0	+	+++	+++	+++
UV resistance	+++	+++	++	0	+	+
Skin oil resistance	+	+	+	+++	+++	+++
Dirt Pick-up	0	+	0	+++	+++	+++
Stain Resistance	+++	+	+	0	++	++
Feel	Plastic	Rubbery	Rubbery	Plastic	Plastic	Plastic

0 - Poor: + - Fair: ++ - Good: +++ - Excellent

Table 3: Physical properties of developed overmold compounds.

	Test Method	Units	OM 1245	OM 1255	OM 1262	OM 6050	OM 6065
Overmold Technology			PC/ABS	PC/ABS	PC/ABS	PA	PA
Hardness	D 2240	Shore A	45	55	62	50	65
Specific Gravity	D 792	g/cc	0.97	1.07	1.17	1.17	1.15
Flow 300 % Modulus	D 412	MPa	379	340	583	423	587
Tensile Strenght	D 412	MPa	687	462	1847	473	592
Elongation	D 412	%	589	604	589	485	236
Tear Strenght	D 624	kN/m	140	178	274	156	186
Comp. Set @ 23 C	395 B	%	27	25	18	24	33

Table 4: Adhesion data of developed products in pli units.

	OM1245	OM1255	OM1262	OM 6050	OM 6065
Cycoloy C2950 (PC/ABS)	15	15.5	26.4		
Cycolac T1000 (ABS)	14.5	15.1	27.2		
Lexan 141 (PC)	13.5	17.2	27.1		
Zytel 7331F (PA 6)				21	23.5
Zytel 73G33L(33% GF PA 6)				17.2	19.8
Zytel 101L (PA 66)				22.1	20.7

Table 5: Performance of other commercially available TPE in adhesion performance.

	B-TPE- 65A	B-TPV- 55A	B-TPE- 35A	B-TPE- 50A	B-TPV- 55A	B-TPV- 70A
Cycoloy C2950 (PC/ABS)	12.8	8.1	10.4	15.1		
Cycolac T1000 (ABS)	10.2	9.1	9.1	12.4		
Lexane 141 (PC)	11.7	10.2	8.1	15		
Zytel 7331F (PA 6)					7.2	8.8
Zytel 73G33L(33% GF PA 6)					8.1	8.2
Zytel 101L (PA 66)					6.8	7.2

Table 6: Typical Flow lengths achievable with GLS compounds. Spiral Flow Tests performed on 0.0625 in thick, 0.375 in wide channel at 400°F.

Product Name	Flow Length, in. @ Injection Velocity, 3 in/s	Flow Length, in. @ Injection Velocity, 5 in/s
OM 1245	198	277
OM 1255	174	246
OM 1262	219	379
OM 6050	154	253
OM 6065	155	221
60A S-TPE	226	329
60A TPV	161	228

Figure 2: Weight change when exposed to ASTM 903 oil.

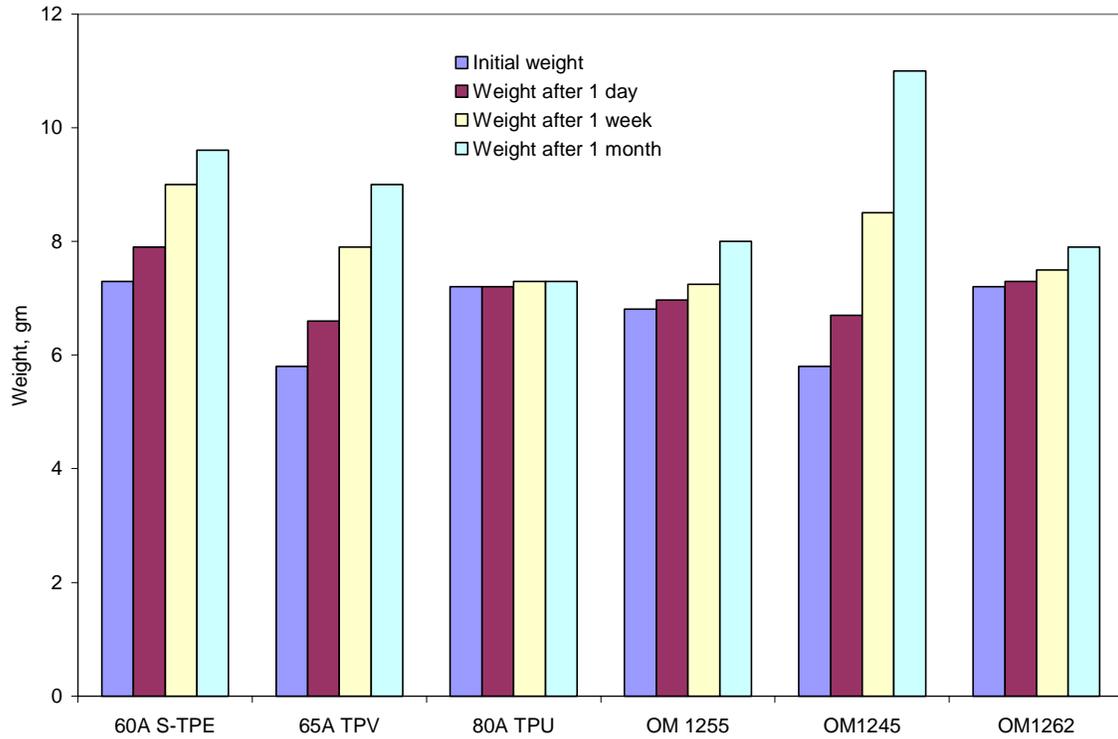


Figure 3: Weight change when exposed to ASTM 903 oil.

