

Overmolding of Thermoplastic Elastomers: Engineered solutions for consumer product differentiation

Krishna Venkataswamy, Rajesh Varma and Walter Ripple, Thermoplastic Elastomers Division, GLS Corporation, 833, Ridgeview Drive, McHenry, IL 60050

Introduction

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), semicrystalline 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 everdemanding needs in ergonomics, aesthetics and value addition in the consumer market.

Overmolding Technology

Over-Molding utilizes the injection molding process to apply one material [*Over-Mold*] onto another material [*Substrate*]. The over-molded material should form a bond with the substrate that endures the end-use environment and offers functional performance. Over-molding eliminates the need for adhesives and primers to bond TPEs to rigid substrates. Overmolding technology offers design flexibility, lower manufacturing costs coupled with ease of manufacture. The two primary over-molding processes are Multiple Material Molding and Insert Molding.

Multiple Material Molding

Multiple Material Molding is also sometimes called multicolor or two-shot injection molding. Specialized machines, which have two or more injection units, are used, as shown in Figure 1. The injection machine barrels can be configured parallel or perpendicular to each other. The mold consists of two sets of cavities. One set molds the substrate and the other molds the overmolding material.



Figure 1.: Two shot injection molding machine with parallel barrels. (Photo courtesy of Nissei Corp of America)

The two shot molding processes include two steps. In the first step, the first barrel fills the substrate set of cavities. After the substrate has cooled, the mold opens and the movable side of the mold rotates 180° without ejection of the substrate. In the second step, the mold is closed and second barrel injects the over-mold material and fills the second half in the stationary side of the mold. If the over-mold material is to be molded on both sides of the part, the mold may shuttle the parts between two different sets of cavities, instead of rotating.

Rotary Die v/s Rotary Platen Machines: In some cases, the rotation is built into the machine in the form of a rotary platen on the second half of the press. If a rotary platen is used four independently, mounted mold halves are usually used. In other cases, the rotation may be built into the tool and there are only two mold halves but four sets of mold cavities.

Moving -Core process uses a hydraulic or air operated moving element in the tool. After the first substrate has been injected and allowed to cool, a mold segment retracts forming a cavity for the TPE over-mold material. The TPE is then injected, usually from the side of the cavity exposed when the insert retracts. The advantage of this method is faster cycle times, higher cavitation, and machine efficiency. The limitation is only a uniform thickness of TPE can be applied.

Insert Molding

During insert molding, a pre-molded rigid plastic substrate or metal part is inserted into the cavity via robotics or an operator (Figure 2). The second (over-mold) material is either injected onto one side of the insert or sometimes completely surrounds the insert. Insert Molding uses conventional injection molding equipment.

Rotary or Shuttle Table Molding : A substrate is molded or an insert is placed in the second cavity in the first position using a horizontal injection unit or a robot. The table rotates or shuttles to the next station where the TPE is injected using another horizontal or vertical injection unit. The runner may be placed at the parting line or

a hot sprue may be used. For the rotary unit, a third rotation moves the table to an “off-load” station where the completed two component part is ejected.

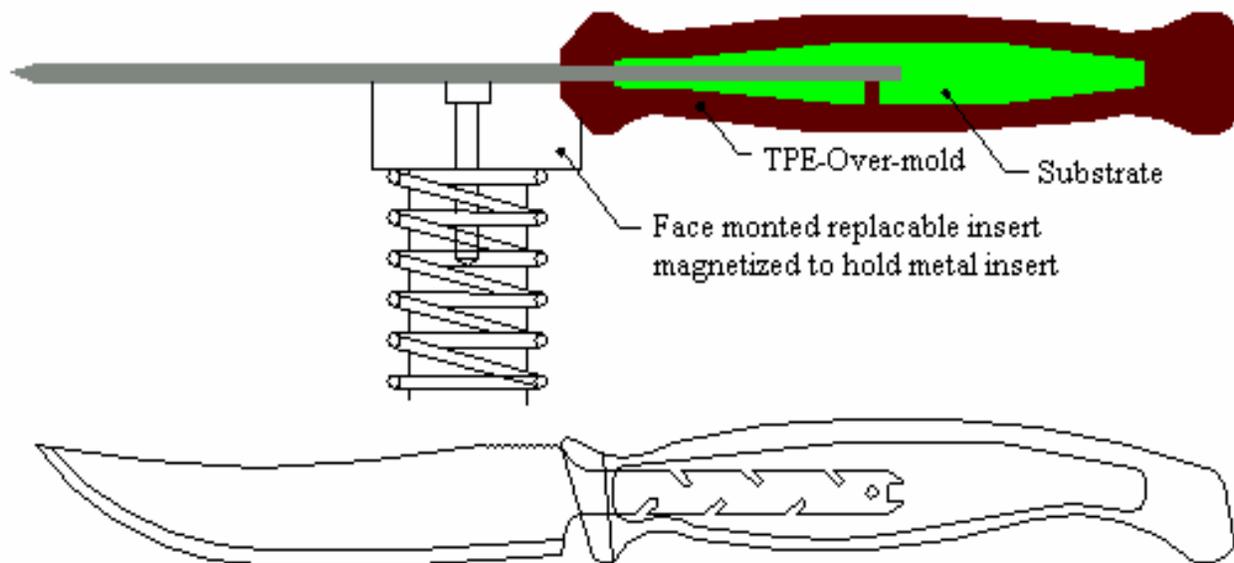


Figure 2. Spring-Loaded insert for Metal Tolerances

Over-molding Process Selection

The decision which of the possible processes and mold design to select depends on material selected, labor costs, available tools and machines, production scale economics. Insert molding must be used if the substrate insert is not a thermoplastic. Hand inserting of the plastic or metal substrate is advisable if the volumes required are low, local labor costs are low, and tooling cost must be kept low. Shuttle presses may be used for higher production quantities. Robotically placed inserts and rotary table machines may be used where production requirements justify the expense. If the production quantities are large and/or the local labor cost is high, two material molding machines are advisable for plastic substrates; hot runner systems using valve gates are advisable for highest production volumes and the best part aesthetics.

Design Considerations

The design aspects for overmoldings are very intensive and some general considerations are discussed in this paper. More details are available in other publications.²

The material requirements of bondable TPE's are more stringent from conventional TPE's. Same holds true for designing parts. Unlike conventional part design, two component part designs have to take into consideration shrinkage's from two different thermoplastic materials. Both have their own gate and runner system and need to be tailored to the specific material properties used.

The wall thickness of the substrate and over-mold should be as uniform as possible to obtain the best cycle time. Wall thickness in the range from 1 mm to 3 mm will ensure good bonding in most over-molding applications. If the part requires the use of thick sections, they should be cored out to minimize shrinkage problems and to reduce the part weight and cycle time. Transitions between wall thickness should be gradual to reduce flow problems such as back fills and gas traps. The use of radii (0.5-mm minimum) in sharp corners helps reduce localized stress. Deep unventable blind pockets or ribs should be avoided. Long draws should have a 3-5° draft to help ejection. Properly designed deep undercuts however are possible with over-mold compounds if an advancing core is used when the mold opens and the part does not have sharp corners and the elastomer is allowed to deflect as it is ejected.

Most TPE compounds have fairly high mold shrinkage in the flow direction with minimal shrinkage in the cross flow direction. This can lead to the over-molding compound contracting more than the substrate after the part is ejected from the tool. This, in turn, can result in a warping or cupping of the substrate part, usually in the direction of flow of the overmolding material. This is especially true for long, thin parts or parts where the substrate is thinner than the over-mold or if a low modulus substrate material is used. This can be partially counteracted by using higher modulus substrate materials and providing stiffening ribs in the substrate. Thinner

coatings and the selection of a lower hardness over-mold grade will also help. Relocating the gate to influence the TPE flow pattern may also be of assistance.

TPE materials are quantified based on Shore hardness, which is a material's resistance to indenture on a 6.3-mm minimum thickness molded plaque (ASTM D2240). A lower hardness product has a softer feel on the surface for the same thickness product. But since overmolding is usually limited to thin skin of TPE, the softer feel is influenced by the hard substrate underneath. If a hardness test is done in this case a lower indenture will be observed resulting in higher hardness even though the skin may be soft. If the elastomer over-mold is to be present on both A and B sides of the parts two material molds that shuttled or rotated between mold sections must be used. Two material molds using moving cores should be used to form a uniform coating on a portion or the complete side of a simple part. Depending on the wall thickness of the elastomer and the substrate, the production rate can be very high.

Thermoplastic Elastomers for Overmolding Applications

The growth of the thermoplastic elastomers continues over the last three decades and the projections are very optimistic³. In the consumer market area, the overmolding applications include consumer non-durables, hand held electronics, housewares and computers. The market demand for newer TPE solutions is very imminent with the range of thermoplastics being used.

Thermoplastic elastomers are classified by their chemistry⁴ as follows. Each of the chemistries offer the properties governed by the building blocks.

1. Styrenic block copolymers
2. Olefinic Copolymers
3. Thermoplastic Vulcanizates
4. Thermoplastic Urethanes
5. Copolyesters and
6. Copolyamides.

They are usually classified by the service temperature and oil resistance describing their performance as per ASTM D 2000 classification as in Figure 6. This classification is very valid, if the end-use application is automotive under the hood application or the elastomer is exposed to high temperatures and oil. In the consumer applications, the elastomer performance needed is processability, colorability and softness. In consumer applications, the classification as in Figure 7 is more pertinent.

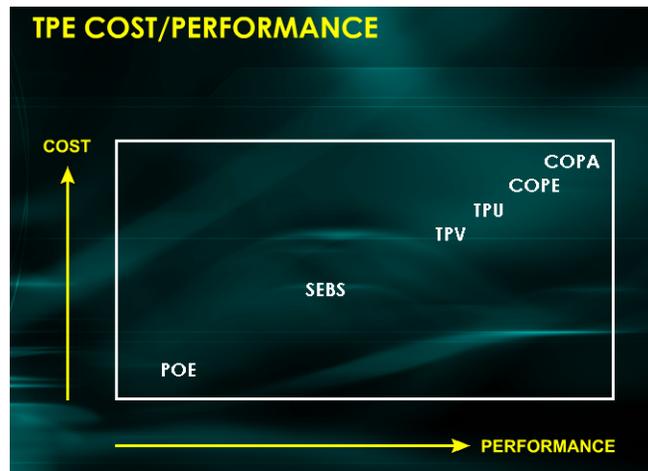


Figure 6: Typical Classification of TPEs based on ASTM D2000

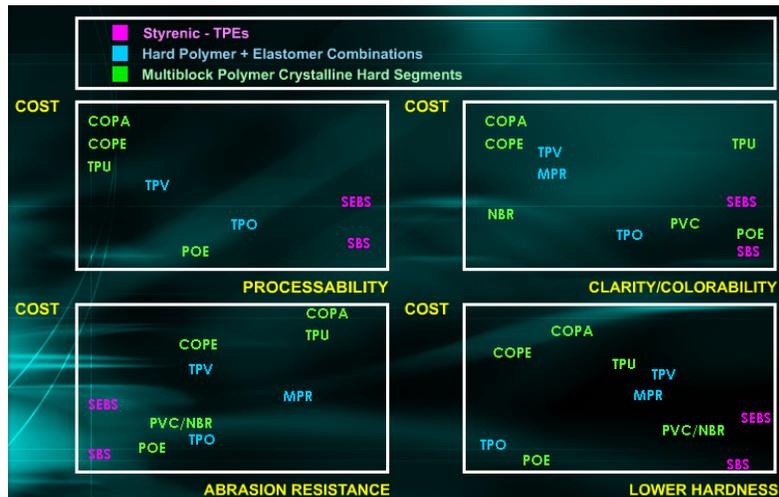


Figure 7. Price –Performance applicable for consumer overmolding applications

The chemistry of the TPE can be limiting in terms of the substrate it can be bonded to. As an example, in order to bond to engineering thermoplastic, the continuous phase in a TPV has to be modified significantly.

Polypropylene which is normally the continuous phase in a TPV does not lend itself for functional modifications needed to meet the adhesion requirements for a wide variety of engineering thermoplastics that are being used in the consumer market.

The TPE compounds developed at GLS bridge the gap of the above chemistries and offer solutions to customers with adhesion requirements for substrates ranging from Polypropylene to Polyamide which represent the opposite spectrum of polarity. Breakthroughs in proprietary alloying technology and compatibilization have made it possible to offer material solutions with substrates of varying chemistries. Most Dynaflex[®] (Styrenic block copolymer TPE), Versaflex[®] (polar modified alloys) and Versalloy[®] (TPV alloy compounds) are suitable for two-shot or insert molding with a polypropylene (PP). The Over-molding (Versaflex[®] OM Series and Versollon[™] which is a Urethane alloy) grades are specially formulated to bond to a variety of substrates. The substrates vary in chemistry. They include amorphous polymers such as polystyrene (PS), High Impact Polystyrene (HIPS), Polycarbonate (PC), Acetal (POM), PC/ABS, Acrylonitrile Butadiene Styrene (ABS), Polyphenylene oxide (PPO), Noryl[®] (a miscible blend of PS and PPO), and PC/PETG. Selective commercial grades of TPEs and developmental TPEs bond to crystalline polymers such as Acetal (POM), Nylon 6, Nylon 6,6, Copolyester, Polybutylene terephthalate (PBT).

The selection of TPEs for a given substrate depends on the level of adhesion needed and the required functional performance in the end use application. Depending on the end use application, the specific TPE product can be specified. Thermoplastic elastomers with varied chemistry are available to meet the end use requirements.

Adhesion of TPE with Engineering Thermoplastic

The adhesion between hard engineering plastic and soft elastomer depends on a lot of variables. Matching the surface energy on both materials is critical for building specific interactions between materials. Another important variable is wettability of TPE on substrate surface. For specific interactions to occur between the TPE and the substrate, both have to come in intimate contact to each other and wet-out the surface. The wet out characteristic is determined by the rheology of the TPEs as shown in Figure 3. Over-molding compounds have relatively low viscosity. Furthermore, they are shear -sensitive and exhibit shear thinning behavior.

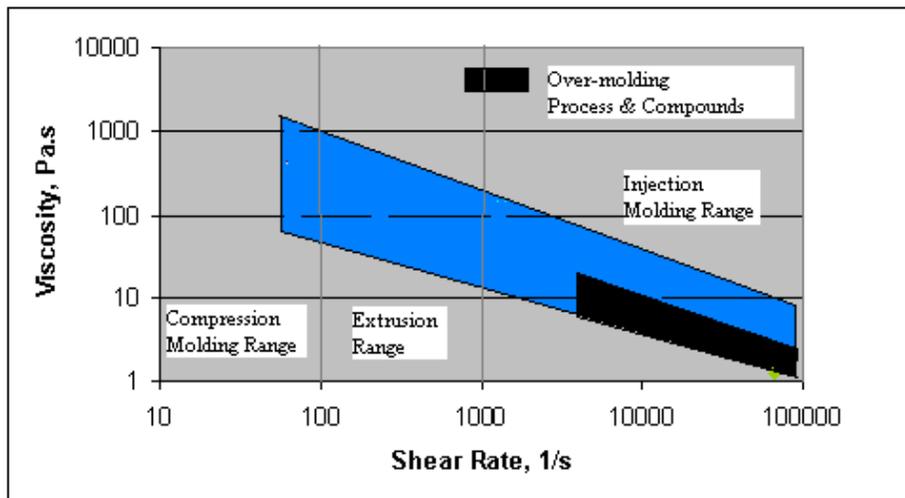


Figure 3: Rheological behavior of Over-molding TPEs

The viscosity is in the lower end of the spectrum as shown in the figure 3. in high shear rate regimes. This helps TPE flow into and fill thin walled sections commonly encountered in over-molding.

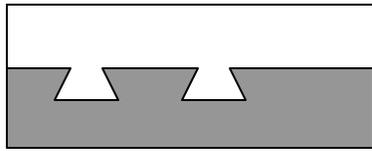
TPE chemistry and the type of engineering plastic play a critical role in influencing wettability. In addition the diffusion, viscoelastic properties of the elastomer have an influence on the adhesion properties as well.

The interface of the TPE and rigid substrate plays a vital role in determining not only the bond strength, but also the type failure; i.e. Cohesive (C) or adhesive (A). The cohesive mechanism is generally regarded as the

preferred mode of failure for indication of good bond strength. However, a weak TPE with marginal bond strength can create an illusion of good bonding. In some instances, good bonding exists even in the mechanism of adhesive failure. Three types of mechanisms at the interface can facilitate bonding of the soft thermoplastic elastomer and the rigid substrate. These are illustrated in Figure 4.

Mechanical interlock is achieved through design. In this situation any TPE will work, but a true bond between the two surfaces is not accomplished. The second mechanism is through chemical compatibility of the substrate and the overmolding TPE compound. Chemical compatibility depends on the surface energies which are related to the cohesive density match between the substrate and the TPE. Depending on the molding method and the temperatures, an interface can be formed where there is a molecular mixing of the substrate and the overmold. As an example, a styrenic TPE or an olefinic TPE molded on to polypropylene as the substrate can have an interface. The third mechanism can be designed into the TPE where specific polar interactions or chemical reaction between the groups of the TPE and the rigid substrate offers the bonding mechanism.

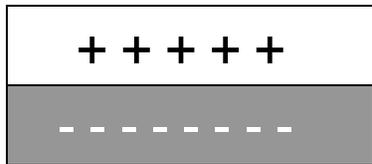
The bond strength between the TPE and the engineering plastic can be measured by performing a "90° Peel Test". We have modified ASTM D903 method for plastics to evaluate the adhesion of soft TPE onto rigid thermoplastic. A schematic diagram of this test procedure is shown in Figure 5. The testing is done on a molded substrate with a TPE skin insert molded on it. An inch wide strip of TPE is cut and pulled at 90° to the substrate using an Instron tensile tester. The substrate is locked in its place on wheel in order to maintain the 90° angle while the elastomer is being pulled. The adhesion strength is measured by the force required to pull the elastomer from the substrate and is reported as an average over 2 inches of pulling. The adhesion is categorized based on adhesive failure (A)- if no TPE residue is left on the substrate or cohesive failure (C)- if the failure is in TPE. The reported values are an average of three different adhesion tests. Based on adhesion strength required by the consumer we have categorized an adhesion value higher than 12 pli to be acceptable for adhesion.



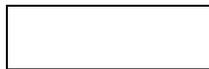
Mechanical Interlock



Chemical Compatibility
(Interface formed due to favorable interfacial tension and melt viscosity)



Specific Interaction (e.g.. Chemical bonding such as Hydrogen Bonding)

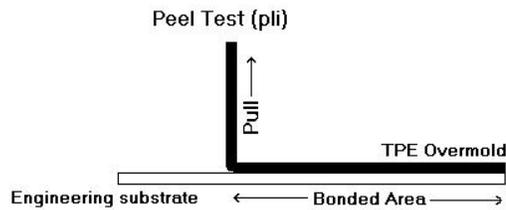


=Overmold



=Substrate

Figure 4: Mechanisms of bonding between TPE and rigid substrate



July 19, 2007

Figure 5: Schematic diagram of peel adhesion testing. Data is reported in pounds per linear inch (pli).

Overmolding Examples

Specific examples of TPEs are chosen for discussion with rigid substrates. The TPEs vary in chemistry and alloying technology to meet the needs of the rigid substrates chosen for discussion. The list is far from being comprehensive of the available technical solution from our work. Selected overmolding TPE grades from a family of polar modified styrenic block copolymer compounds commercially available under the trade name Versaflex^R with their physical properties are tabulated in Table 1.

Table 1: Physical Properties of Typical Overmolding TPEs

	TPE-A	TPE-B	TPE-C	TPE-D	TPE-E	TPE-F	TPE-G
Hardness:	40	60	45	55	62	50	65
Specific Gravity:	0.92	0.93	0.97	1.07	1.17	1.17	1.15
Flow/Cross 300% Modulus:	292	472	379	340	583	423	587
Flow/Cross Tensile Strength:	587	628	687	462	1847	473	592
Flow/Cross Elongation:	593	532	589	604	589	485	236
Flow/Cross Tear:	107	148	140	178	274	156	186
CS 22hr. @ 23 C	18	28	27	25	18	24	33

The specific gravity range from 0.92 to 1.17 with a range of hardness for the overmolding application. The tensile properties are typical for thermoplastic elastomers. These TPEs are not designed for low compression sets at elevated temperatures as the functional use on typical overmolding applications is ambient.

Table 2 lists the TPE products that were overmolded onto different substrates along with their adhesion test data. For PC, ABS and PC/ABS, the adhesion values are plotted in Figure 8. Table 4 gives the adhesion performance of other commercially available TPE products for overmolding on various substrates. TPEs in Table 4 are styrenic materials where as TPVs are the dynamic vulcanizates of polypropylene and EPDM. These have been processed at the manufacturers recommended molding conditions.

Comparing data from Table 3 and Figure 8. with Table 4, it can be seen that polar modified styrenic TPES (in Table 1) outperform other TPEs.

Table 2: Adhesion Values (pli) for Typical TPE grades which are polar modified styrenic block copolymers

	TPE-A	TPE-B	TPE-C	TPE-D	TPE-E	TPE-F	TPE-G
Cycloy C2950 (PC/ABS)	12.4 A	16.7 A	15 A	15.5 C	26.4 C		
Cycolac T1000 (ABS)	11.9 A	17.8 A	14.5 A	15.1 C	27.2 C		
Lexan 141 (PC)	12.2 A	14.5 A	13.5 A	17.2 C	27.1 C		
Zytel 7331F (PA6)						21 A	23.5 A
Zytel 73G33L (33% GF PA6)						17.2 A	19.8 A
Zytel 101L (PA66)						22.1 A	20.7 A

Table3: Adhesion Values (pli) for commercially available TPEs.

	B-TPE-65A	B-TPV-55A	B-TPE-35A	B-TPE-50A	B-TPV-55A	B-TPV-70A
Cycloy C2950 (PC/ABS)	12.8 A	8.1 A	10.4 A	15.1 A		
Cycolac T1000 (ABS)	10.2 A	9.1 A	9.1 A	12.4 A		
Lexane 141 (PC)	11.7 A	10.2	8.1 A	15 A		
Zytel 7331F (PA6)					7.2 A	8.8 A
Zytel 73G33L (33% GF PA6)					8.1 A	8.2 A
Zytel 101L (PA66)					6.8 A	7.2 A

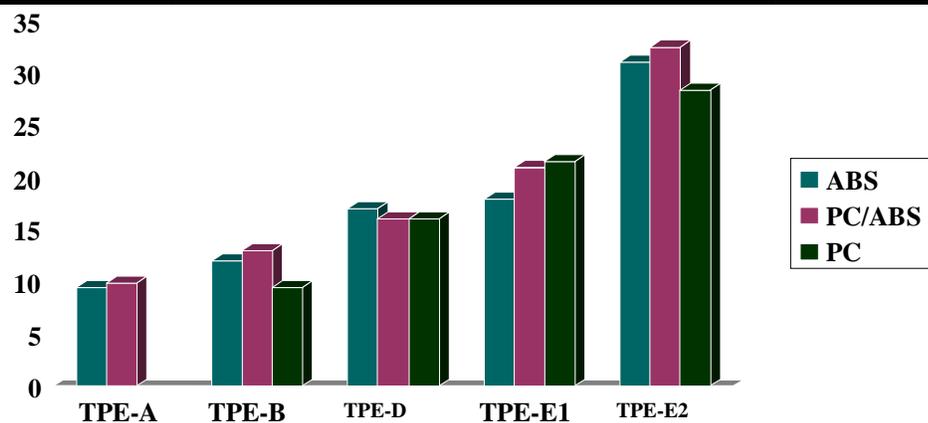


Figure 8: Adhesion values of TPEs with rigid substrates, ABS, PC and PC/ABS

Consumer Product Differentiation

Today there is phenomenal interest in overmolding TPEs onto rigid substrates, particularly in the consumer product arena in applications requiring a soft touch. The influx of new TPEs being overmolded onto an ever-growing list of substrates offer the designer greater design freedom and the ability to further differentiate their products in a market full of “me-too” imitations.

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. New colors, textures, designs, comfort – these and more are all compelling reasons to choose a product that features an overmolded TPE surface. 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. 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 vibration cushioning. Overmolded TPEs can also provide functionality beyond feel and ergonomics. Examples include 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.

From a marketing perspective, these compounds are ideally suited for a variety of consumer product applications including hand & power tools, business machines and hand-held electronics, personal care items, appliances, and sports & leisure.

Hand & Power Tools: The ever increasing desire for more ergonomic, soft-touch designs in our culture is driving more and more suppliers of hand and power tools to seek ways to add value to their products by making them more comfortable, practical, and durable (Figure 9) . TPEs provide a number of benefits to address these market trends such as a soft-touch, non-slip grip, while maintaining required performance properties such as good oil/grease resistance, toughness, abrasion resistance, and vibration damping. The overmolding process also provides ergonomically correct tools to enhance worker safety. Tool manufacturers are able to enhance

sales by providing attractive designs that are only available from soft, colorable, thermoplastic elastomer overmolds.



Figure 9: TPE Overmold creates value in Hand Tools Ergonomics

Electronics/Office Equipment: TPE overmolding in this market area is growing at a rapid rate. The primary needs for consumer electronics are for comfortable soft-touch feel, differentiable design capability, and durable elastomer performance. TPEs, especially through design flexibility and colorability, provide the OEM and molder with the capability to add marketable value-added features to their products. In many cases, overmolded hand-held products require a low coefficient of friction such that they can be easily slid in and out of pockets and on counter surfaces. Wear and UV resistance, as well as resistance to dirt and skin oil are also important.



Figure 10. TPE Overmold offers differentiation for electronics.

Example applications include handles, grips, bumpers, keypads, and housings on cellular phones, pagers, PDAs, PCs, laptops, printers, headsets, video, and hand-held computers.

Personal Care: Soft touch overmolded TPEs are widely used in personal care applications such as handles and grips on hair brushes, razors, toothbrushes, and writing pens/pencils. The consumers' preference for a soft touch, "warm" feel and a personalized color palette drives the use of TPEs in personal care products. Some applications also require resistance to various mild chemicals or oils depending on the environment experienced. TPEs allow for products that have more perceived value for the customer, and provide the OEM with an avenue to create a marketable differentiated product in a very competitive market segment.



Figure 11: TPE Overmold offers soft grip in handle applications in personal care

Appliances: Ergonomic, soft touch grips and other surfaces as well as differentiable aesthetics drive the expanding need for overmolded TPEs in the appliance segment. Soft touch grips, knobs, and buttons are increasingly being targeted for TPE overmolding. Small kitchen appliances such as coffee makers, food processors, and electric knives require a good non-slip grip, stain resistance, and cleaning solution resistance

properties, while floor-care products require soft touch, vibration damping, excellent aesthetics, and durable long wear properties. Other applications include irons, blenders, grills, toasters, grinders, refrigerators, and ovens.

Sports and Leisure: Designers for sports equipment and accessories as well as snow mobiles and water recreation vehicles are increasingly turning to overmolded soft touch TPEs to provide the functionality and design freedom that they need. Aside from their soft touch, non-slip grip, even in wet environments, TPEs offer good weatherability, good chemical and oil resistance, low temperature flexibility, and good wear resistance. Applications include handles, knobs, foot rests, and flaps on water recreation, snow mobiles, and motorcycles; handles and grips on knives, fishing gear, jet skis, and tennis rackets; and other various sports equipment.



Figure 12: TPE Overmold offers comfort and non-slip grip in Liesure

Conclusion

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.

Reference:

1. G. Holden, "Application of Thermoplastic Elastomers", 573, Thermoplastic Elastomers, 2nd edition, 1996
2. GLS Overmolding Guide, 2002
3. Handbook of Thermoplastic Elastomers, G.Holden, N.R.Legge, R.Quirk and H.E.Schroeder. 1979
4. ASTM D2000, American Society for Testing and Materials, Annual Book of ASTM Standards, Vol9, 01, 1994

About Authors:

Krishna Venkataswamy is the Director of Research and Development, Rajesh Varma is Application Development Manager and Walter Ripple is the Director of Marketing for the Thermoplastics Elastomers Division of GLS Corporation, 833, Ridgeview Drive, McHenry, IL 60050