

Development of Gas Assist Injection Molded TPO Side Protector Molding

ガスアシスト射出成形によるTPOサイドプロテクタモールの開発

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要 旨

ホンダのサイドプロテクタモールシステムの歴史は、押出し成形法によるPVCの使用が主流であったが、ガスアシスト射出成形方法の導入により新たな領域へ適用の可能性を広げている。押出し成形はPVC材料を使用しているのに対して、ガスアシスト射出成形は、TPOを使用している。成形品は軽量で外観も良く安価、さらにPVCを使用しないことより環境にやさしいものとなっている。

ここでは、96年モデルのシビックおよびアコードのサイドプロテクタモールに採用された新プロセスのガスアシスト射出成形法および材料開発について述べる。また、この工法の将来的な方向性についても言及する。

ABSTRACT

The history of the Honda side protector molding systems is dominated by the utilization of PVC and the extrusion molding process. The application of the gas assist injection molding process opened up possibilities in new application areas such as the side protector molding for which the extrusion molding process has been the previous process of choice. Whereas the extrusion process used PVC type materials the new product using the gas assist injection molding process uses TPO. The product resulted in a lighter, more aesthetic and lower cost part which also, by virtue of PVC elimination, is more environmentally friendly. This paper discusses the development of the material and the application of the new gas assist molding process which were necessary in the realization of the new gas assist injection molded side protector molding introduced in the 96 model year Civic and Accord. The future direction for this application is also discussed.

1. History of Honda's side protector molding systems

The extrusion molding process has been the predominant process for Honda side protector molding systems quantitatively. In addition to their continuous usage from the model introductions of the Civic and the Accord, these systems are also used in the Prelude, Integra and Odyssey models as well. These side protector molding systems are produced by coextruding roll-formed steel ribbon with PVC after which the ends are formed through a PVC injection molding operation.

These side protector moldings also feature in plastic clips as the primary means of assembly of the door skin.

The only other type of system that Honda has employed up to the 95 MY was TPO or PVC injection molded 1 piece type with metal insert (Fig.1). This system was developed for the 91 MY Acura Legend to achieve a seamless high quality appearance.

The new gas assist injection molded system represents the third and the latest major development in the evolution of Honda side protector molding systems (Fig.2). This new system was developed for the 96 Civic

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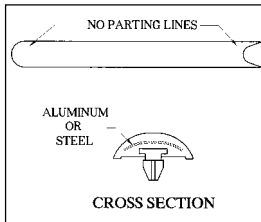


Fig.1 Metal insertion with TPO or PVC

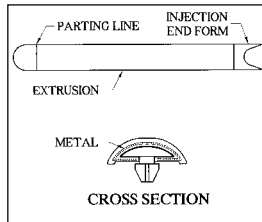


Fig.2 Roll formed extrusion with end injection

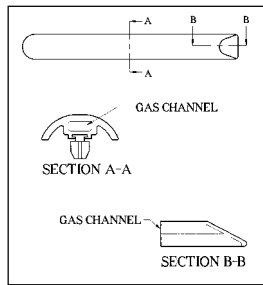


Fig.3 Gas assist injection

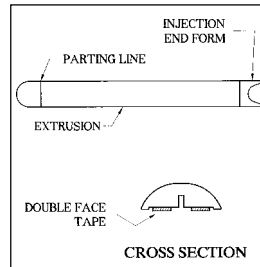


Fig.4 Solid PVC with end injection

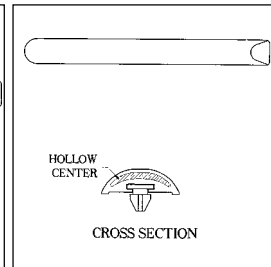


Fig.5 Blow molded PP

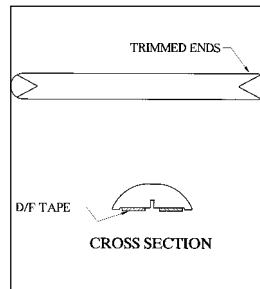


Fig.6 Solid PVC extrusion

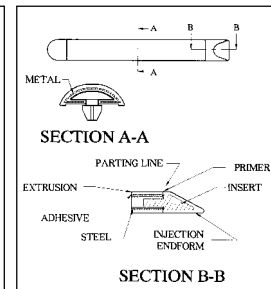


Fig.7 Roll formed extrusion with end injection

and Accord, and has recently been extended to the new Acura CL model as well. As indicated in Fig.3, the new system features in a gas channel and has no parting lines in the show surface for a seamless appearance.

2. Industry overview

In addition to the Honda side protector molding systems, there is a variety of constructions that have been and are being used in today's industry. One of the most popular constructions is the extruded solid PVC with injection molded ends (Fig.4). This system, in contrast to the Honda's old PVC extrusion system, does not incorporate roll formed steel. It primarily relies on application of double face tape for assembly onto the door panel.

Blow molding has also been utilized to produce side protector molding systems (Fig.5). Although the core of the part is hollowed out, the processing hardware as well as the molding concept is fundamentally different from the gas assist injection molding process. The part appearance, particularly with respect to both surface quality and overall dimensional accuracy is vastly different in comparison to those of the gas assist or injection molded variety.

Finally, for extrusion molded PVC systems, one way to avoid parting lines at the ends is to simply perform a crude trimming operation and forego the end injection molding step altogether (Fig.6-7). While being one of the simplest and cheapest of processes, it comes at a cost of sacrificing aesthetics.

3. The old side protector molding system

3.1. Anatomy of the old PVC side protector molding system

The PVC extrusion side protector molding has a coextruded cross section with roll formed steel as a reinforcing support. In the PVC extrusion process, steel sheet is roll-formed prior to being coextruded with PVC. The steel reinforcement provides a number of attributes to the PVC extruded side protector molding system.

First, it provides strength and stiffness to an otherwise non-rigid part.

Second, it facilitates accurate cross sectional profile control of the side protector molding while at the same

time allowing minimal PVC material usage for the given exterior appearance and dimensional requirements.

Finally, it provides CLTE (Coefficient of Linear Thermal Expansion) control for the final assembly. Compared to a solid PVC extrusion part, less amount of PVC material is used in achieving a given exterior shape appearance. As shown in the cross section illustration of the injection molded end area, the parting line in the Honda side protector molding is a complex marriage of different interfaces of a variety of materials which include the PVC, steel, adhesive, primer, and a Polyacetal insert piece which acts as the primary reinforcement of the weld line. The development of the weld line reinforcement insert, primer, and the geometry of the mating surface at the weld line required tremendous attention in order to overcome separation problems caused by the paint cure temperatures.

3.2. PVC materials

For the unpainted black side protector molding application, a 78-shore-A-durometer-Phthalate plasticized PVC was used. For the painted application, a Polyester modified PVC type material was developed. This material incorporates a Polyester additive as a plasticizing agent and it provides excellent paint adhesion performance in comparison to a conventionally plasticized PVC which has the problems for the growing yellowish associated to plasticizer migration into the paint layer. Unfortunately, this paintable PVC material was unavailable in North America and consequently had to be imported from Japan. As a result, it was a costly part to produce in North America, and material minimization and manufacturing scrap rate reduction particularly for the painted side protector molding design became important issues for design and manufacturing.

4. New side protector molding system

4.1. Summary of the major changes

In contrast to the PVC extrusion system, the new gas assist injection molded system is the result of an

elegant simplification of design, material and process.

First, the design is of one piece construction which eliminates the parting lines by design. The gas channel yields the increased part stiffness while minimizing material usage.

Second, the manufacturing process has been greatly simplified primarily as a result of a reduction in the total number of processing steps involved.

Third, the construction consists of only one material, TPO. The TPO material was developed to achieve an optimum balance of impact performance, thermal expansion, and paint adhesion performance in addition to gas assist injection processability and final part appearance. As it is discussed later, this new system offers a myriad of benefits over the previous side protector molding systems.

The manufacturing process has been greatly simplified with the adoption of the gas assist injection molding system. First, in the previous system, the manufacturing process begins with the extrusion process in which the steel is roll formed. During this step the adhesive is applied to the steel and then cured. Next it is coextruded with PVC and cooled. Then it is cut at the length prior to being staged for the end injection molding process. Sanding and polishing stage of the parting lines takes place before it is sent to the finishing stage. Clips and D/F tape are applied next. They are then painted, inspected, then shipped to the Honda manufacturing plant. In the new process, the numerous series of processing steps involved in the extrusion and the end injection molding processes are simplified to just one gas-assist-injection-molding process. One of the many benefits associated with this simplification is a dramatic reduction in plant space requirement.

The new gas-assist-injection-molding process simplifies the manufacturing process by reducing the total number of process steps and eliminating the costly labor required in the sanding of the parting line and finishing of the PVC extrusion part (Fig.8). The new side protector molding is a one piece gas assist injection molded part, and as such, has no weld lines at the show

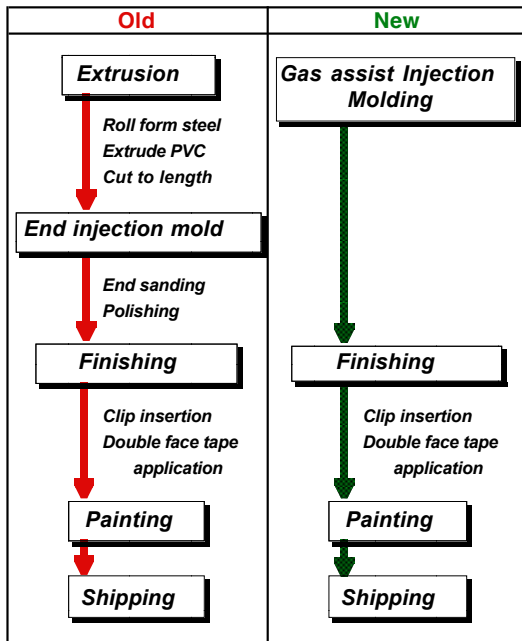


Fig.8 Process comparison

surface while the PVC extrusion part is a three piece part (one extrusion segment and two injection molded end pieces) which has a weld line at each end. This was an appearance concerned and required constant attention at the manufacturing floor. The gas channel shown in the new system provides a number of positive attributes to the part.

First, the boxed geometry of the gas channel provides overall part rigidity.

Second, the gas channel facilitates a relatively stress free molding and packing of the resin, yielding good part straightness which is critical for the overall finished part appearance.

Third, by utilizing a remote surface on the backside of the gas channel it was possible to freely design in clip retainer housings without sink marks or read-throughs on the show surface.

4.2. Gas assist injection vs injection process

Gas assist injection process was compared with a conventional injection molding process, and the following were the main conclusions. Compared to gas assist process, the conventional injection molding

process:

- 1) Required higher mold clamping force (a larger tonnage and hence more expensive machine was required).
- 2) Displayed higher levels of molded in stress making it difficult to achieve desired part straightness.
- 3) Required longer cycle time in order to counterbalance the opposing phenomena of flashing and underpacking of the ends.
- 4) Displayed flow marks when the attempts were made to improve packing by raising the mold and resin temperatures.
- 5) Displayed read-through/sink marks of the clip retainer housings.

Finally, the gas assist injection process was chosen over the conventional injection molding process. The deciding factor was that the gas channel can act as a “runner” to facilitate the resin packing.

4.3. Gas assist injection process pressure profile

Fig.9 illustrates the five critical stages of the gas assist process. The resin is injected into the side protector molding cavity as in a normal injection molding process. At this stage, the Nitrogen gas pressure is also slowly raised at the gas nozzle. The resin pressure and gas pressures continue to build until the resin flow front has cleared the end of the main cavity. At this point, the resin nozzle is shut off and the Nitrogen gas is introduced through the nozzle into the cold runner.

Since the gas pressure takes over from this stage, the reciprocating screw can at this point begin retracting to prepare for the next cycle. This has a benefit of reducing the overall cycle time. The introduction of gas is inhibited up to this point because if it is introduced while the resin is still traveling down the main cavity, hesitation marks would easily form on the show surface of the part. Earlier attempts to control the pressure transfer timing to within the main cavity were unsuccessful as hesitation marks and resin volume control of the screws proved difficult. Finally it was decided to use an overflow cavity to control both problems. Once the gas front breaks

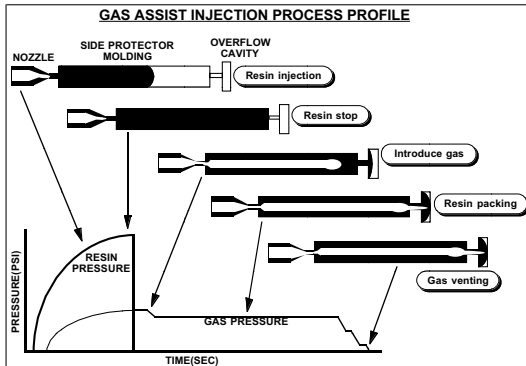


Fig.9 Gas assist injection profile

through the gate into the main cavity it quickly and smoothly traverses the length of the part following the path of least rheological resistance. The path of least resistance, of course, is determined primarily by the cavity geometry. More specifically the gas channel cross section profile. The resin material in closest proximity to the tooling walls will cool and solidify first. It forms barriers to guide the gas front through the molten resin within the gas channel. As the advancing gas front displaces the molten resin, it also packs out the resin into the cavity walls. During the pack out process, the displaced resin is pushed out into the overflow cavity. Again, having an overflow cavity allowed us to easily overcome hesitation marks and also channel out the entire length of the part with the gas. Finally, upon completion of the pack out stage the gas pressure is brought down by venting the gas back through the nozzle. The last remaining gas pressure is relieved at sprue break.

4.4. Design considerations for the gas assist process

The design iteration studies resulted in a number of cross section design criteria for optimal part processing, appearance and performance (Fig.10-12).

4.5. Nozzle development

The gas nozzle, in the early stages of development, was not reliable as it was prone to being plugged or

broken. Most of the problems were related to a gas pin that was controlled by a separate valve controller. The gas pin is a very fragile needle controlled by the valve controller which is a complex assembly of components which contaminated with resin required a lot of labor to reassemble after cleaning. This was replaced with a new, simpler valve design incorporating an internal pin which is spring loaded (Fig.13). This made the nozzle smaller and less mechanical. Through this change the durability and reliability of the nozzle system was significantly improved.

<i>Gas Channel Type</i>	<i>Result</i>
Box Type 	Gas Channel Dimension Control Problem
Runner Type 	Best
Multiple Gas Channel 	Weld Line

Fig.10 Gas channel type considerations

<i>Clip housing location</i>	<i>Result</i>
	Bad (Sink mark)
	Bad (Sink mark / Fingering)
	Good

Fig.11 Clip housing location considerations

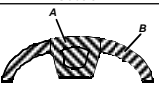
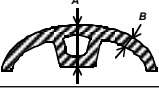
X-Section	Design Control Point	Problems Control
	A/B volume ratio	Knit Line
	A/B dimension ratio	Fingering Impact performance
	A radius	Sink mark Fingering Impact performance
	Gas channel width A	Part weight Gas channel dimension Sink mark

Fig.12 Gas channel design considerations

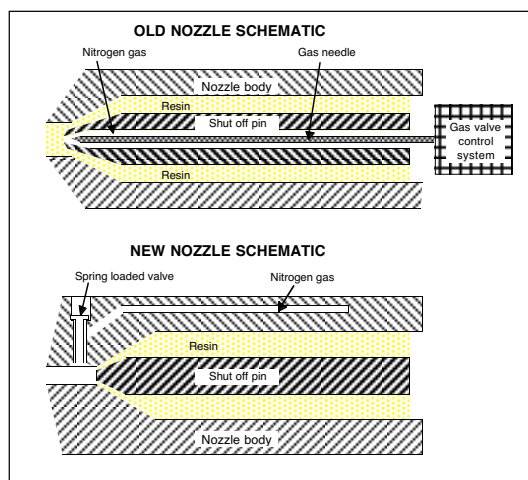


Fig.13 Nozzle design schematics

5. TPO material development

In the new application, TPO was clearly the material of choice. TPO materials are economical, chemical and weather resistant, and are capable of meeting a wide range of physical property constraints for automotive exterior applications. The combined effect of the older PVC material's plasticizer and the polar nature of the basic PVC resin made it susceptible to dirt accumulation on its surface during normal driving

conditions. By choosing TPO family of materials for the unpainted versions, the dirt accumulation problem of the previous PVC versions was eliminated. Moreover, TPO material is consistent with Honda's long history of continued exclusive usage of TPOs in applications such as the bumper fascia (All current Honda bumper fascias with the exception of the Acura NSX are produced of TPO materials) and is also consistent with Honda's commitment to increased usage of recyclable olefinic and thermoplastic (as opposed to thermoset) materials.

5.1. CLTE (Coefficient of Linear Thermal Expansion) control

The PVC extruded side protector molding's thermal expansion was controlled by the use of the steel reinforcement. Hence, it was possible to maintain excellent dimensional control, particularly with respect to overall part length at temperature extremes. As a result, consistent gap control was easily achieved between the door side protector molding and the fender side protector moldings. In the new system, however, the part construction is a single material construction, and its thermal expansion property depends primarily on the intrinsic thermomechanical property of the material itself. Therefore, it was necessary to develop a TPO material with low CLTE. Fig.14 shows CLTE vs EPR rubber content in PP at various temperature ranges. It was discovered that at about 35% rubber content the curve undergoes a minimum for all temperature ranges. It is possible that this critical rubber concentration produces an optimum PP/EPR morphology which results in a positive thermomechanical synergy. In achieving the optimum morphology for minimum CLTE the key was the optimization of the relative viscosities of the PP and the rubber i.e., PP molecular weight and rubber Mooney viscosity. Fig.15 shows mold shrinkage behavior plot transposed to the plot of CLTE vs rubber content in PP. It shows that the mold shrinkage, unlike the CLTE behavior is a linear function of rubber content.

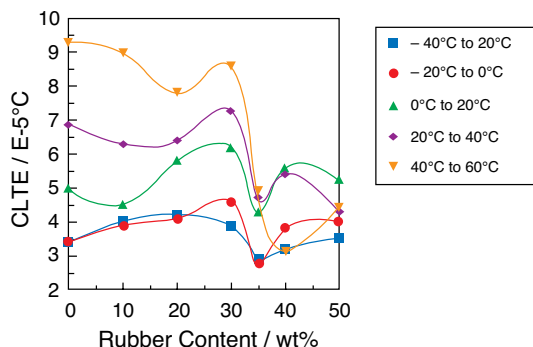


Fig.14 CLTE vs rubber content in TPO

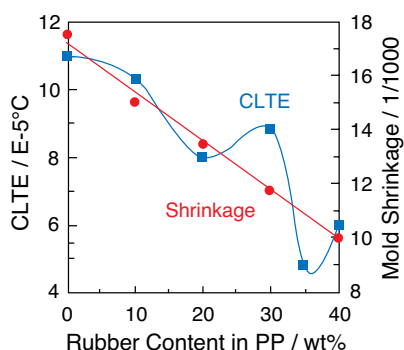


Fig.15 CLTE/mold shrinkage vs rubber content

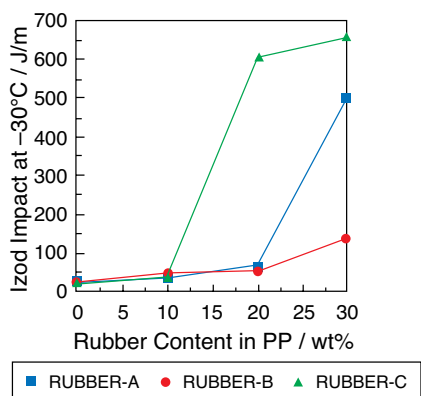


Fig.16 Impact resistance vs rubber content

5.2. Impact performance

Fig.16 shows impact resistance vs rubber content in PP for three different rubber types. As one would expect, higher rubber content yields higher impact resistance. Rubber C shows highest effectiveness in

enhancing impact followed by rubber B and C respectively. It is observed that adjustments in Mooney viscosity of the rubber results in a trade-off between izod impact and melt flow and adjustments in Propylene content in rubber results in a trade-off between izod impact and flexural modulus (and crystallinity). It is also observed that impact resistance enhancements from Mooney viscosity adjustments is dominant in comparison to that of Propylene content adjustments. As shown by Chung, et al.[1], the best balance of properties is obtained by setting both the rubber Mooney viscosity and Propylene content at high levels, and compensate the diminished melt flow and rigidity through adjustments in the PP. When the proper rubber is used, the positive enhancements in impact performance by the rubber will have a more dramatic effect in comparison to the negative effect of the talc on impact property.

5.3. Paintability enhancements

PP is inherently a low surface free energy material and thus poses paint adhesion challenges (Fig.17). In order to render the TPO material paintable, technology for paintable TPO substrate material extensively studied by Komatsu et al.[2] was applied. Paintability of the TPO substrate is achieved in the following three ways.

1) Swelling of the rubber phase.

Swelling of the TPO surface by the primer solvent allows deep penetration of the primer's Chlorinated polyolefins into the substrate for stronger mechanical interaction. The EPDM rubber incorporated in the

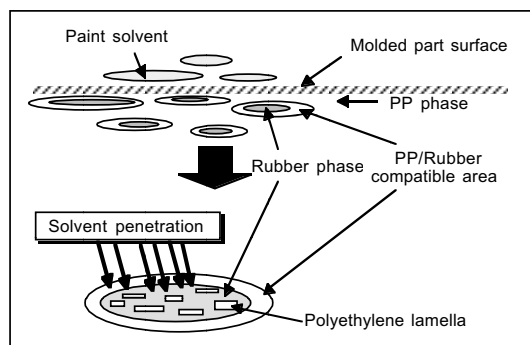


Fig.17 Paint adhesion mechanism of TPO

TPO does have such desired swelling characteristics.

2) Surface morphology.

The manipulation of the EPR and EPDM's relative viscosities with respect to PP near the surface results in a morphology in which the EPDM's shape and total surface area are maximized for optimal interaction with the primer.

3) Polar interaction.

The primer resin has an abundance of polar functional groups capable of simultaneously interacting with both the top-coat and the substrate. However, when the substrate is non-polar, the primer resin's effectiveness is compromised. In order to increase the polar functional sites in the substrate the EPDM terpolymer was chosen (over EPR) with ENB (Ethylene Norbornene) ter-monomer. ENB type EPDM showed strongest adhesive interaction with the primer resins. Overall paint adhesion performance met all Honda requirements (Table 1). Table 1 describes the paint adhesion enhancing EPDM, highlighted in red. Fig.18 shows the material morphology through TEM photography.

Type Rubber	Mooney Viscosity	Propylene Content	Initial Adhesion	Gasoline Resistance
EPM	Low	Low	Pass	Fail
EPM	Medium	Low	Pass	Fail
EPM	High	Low	Fail	Fail
EPM	High	Medium	Fail	Fail
EPDM	Low	Low	Pass	Fail
EPDM	Low	Medium	Pass	Pass
EPDM	Medium	Low	Pass	Fail
EPDM	High	Low	Fail	Fail

Table 1 Paint adhesion performance vs rubber type

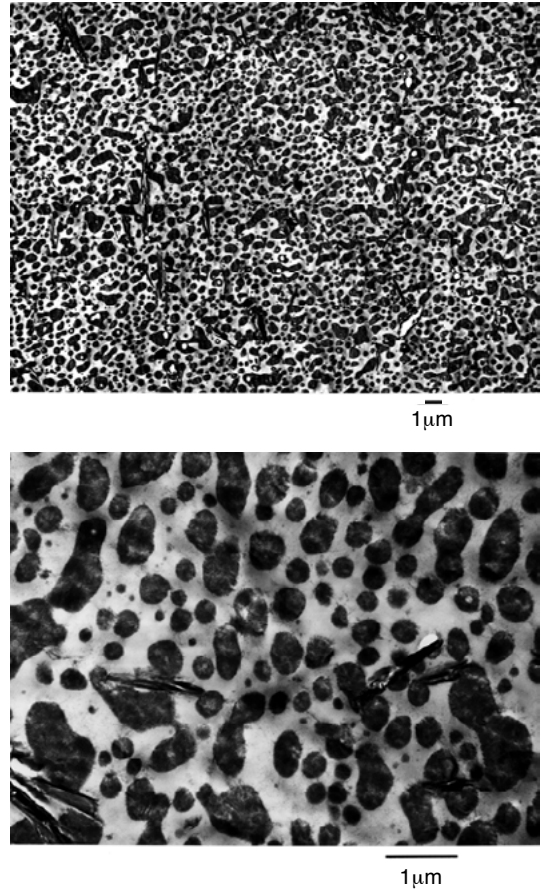


Fig.18 TEM photography of the TPO morphology

5.4. Material adjustments for gas assist injection process

The melt flow of the TPO was fixed at 15g/10 min for optimum processing. Similar to conventional injection molding process, higher melt flow materials generally resulted in good processing characteristics. Mold shrinkage, however, was generally lower than that of conventional injection molding process. This is attributable to the difference in resin flow direction during the part pack-out stage. In the gas assisted resin pack-out, the resin material flows in the direction along the width of the part rather than along the length of the part, resulting in lower packing stress along its length, hence, lower shrinkage occurs along the lengthwise direction. As a result, finer levels of part dimension control is achieved. Table 2 shows the TPO's physical properties.

Property	Unit	Value
Melt flow rate	g/10 min	15
Specific gravity	-	0.98
Flexural modulus	Mpa	1,100
Notched Izod impact -30°C	J/m	170
Shore hardness	D scale	60
Mold shrinkage	1/1000	6-8
CLTE	10E-5/C	4.0

Table 2 TPO physical property

5.5. Simulated part impact performance

Two tests were performed to evaluate the impact performance of the side protector moldings. Steel ball drop impact test was performed, and door impact simulation test was conducted to of the door assembly as a system. In the ball drop test where the steel ball is dropped onto the test part placed on the floor, the TPO part molded using the gas assist process showed no damage up to 14.7 J of impact energy whereas the PVC extrusion part showed damage down to approx. 11.8 J levels. In the door impact simulation test, the test vehicle (96M Accord) was placed side-by-side at a 500 mm door-to-door spacing with a 91M Acura legend 2 door coupe which has Honda's heaviest door. The Acura door was opened at varying opening speeds and the test vehicle was checked for damage to the door skin. The old PVC type impact performance was 1.02 m/sec of door opening speed with damage occurring to both the door protector and the door skin while the new TPO system impact performance was 1.4 m/sec with damage occurring to the door skin only. Clearly the impact performance of the unit part as well as the door system was improved.

5.6. Part length, appearance criteria

Overall length of the 96M Accord door side protector molding is 1104mm. The design clearance from the door's front leading edge to the tip of the door protector

molding was 3.0mm, and the clearance at the trailing edge of the door was 3.5mm. Based on the styling studio judgment for fit and finish total of 6.5mm was the maximum allowable tolerance. Given the above, initial overall length tolerance and maximum overall total heat expansion of +/- 1 mm and +4 mm were set respectively.

5.7. Thermocycle performance

In order to assure good appearance and dimensional compliance to the Honda judgment standards the door side protector molding was assembled onto an Accord door and thermocycled from -30°C to 80°C surface temperature, and changes in part length and appearance were monitored. After extensive testing it was determined that a total of seven clip locations on the side protector molding roughly spaced equally apart and fastened into slots stamped into the door skin would provide optimal level of appearance throughout the thermocycle test. The part was fixed in the middle so that the expansion/contraction would occur in both front and rear directions. Additionally, a double faced tape was applied along the entire lower edge of the molding. In addition to lowering the total part expansion at heat by approx. 0.8mm, the double faced tape eliminates vibrational interference noise for optimal door shutting acoustics.

6. Future Honda developments for the side protector molding system.

The Honda side protector molding system will continue to evolve with the future generations of Honda vehicles. Developmental work is already underway for the next generation of side protector moldings in which the following improvements are targeted:

- 1) Application of recycled materials
- 2) Develop lower VOC coating system
- 3) Achieve further cost reduction.

7. Conclusion

The dual development of the new process and the new TPO material resulted in the following achievements over the previous system.

- ◆1) Environment: The steel reinforced PVC construction has been simplified to an entirely TPO based system which is a more easily recyclable and environmentally friendly system.
- ◆2) Weight: Total of 51% weight reduction was achieved.
- ◆3) Impact performance: The new system provides higher levels of protection to the door skin.
- ◆4) Appearance: Seamless appearance, perfect color/texture matching with the fender protectors which are injection molded TPO. Because the new process is a gas assist injection process, the molding can be designed with freer and more variable cross sectional profiles that are impossible for the extrusion process to achieve.
- ◆5) Localization: Once imported paintable PVC material grade is replaced by a 100% US localized TPO material which contributes to an already highly localized vehicle.
- ◆6) Cost: Total cost savings of 28% per unit was achieved.

With the achievements demonstrated above by the development of the TPO system, Honda plans to add new technologies to this system in the future to achieve even greater benefits to the customers.

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