

Development of Small-sized Multilayer Fuel Tank for Off-road Motorcycles and ATVs

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ABSTRACT

A multilayer polyethylene resin fuel tank for off-road motorcycles and All-Terrain Vehicles (ATVs) has been developed to comply with U.S. EPA gasoline permeation control regulations. Motorcycles and ATVs employ complex saddle-shaped tanks with weld-molded insert parts and requirements for exterior design, and the following four issues were therefore identified and addressed for the multilayer blow molding process. To enable the saddle shape to be molded, pre-blowing and depressuring were employed in the blow molding process in order to achieve a uniform wall thickness. A temperature range that balanced resistance to drawdown in the parison, resistance to melting damage in the insert parts, and adhesion of the insert parts enabled the adhesive strength of the insert parts to be increased. Changes to the design of the modified polyethylene adhesive used to bond the EVOH, which forms a gasoline permeation barrier, have increased the resistance of the insert parts to delamination as a result of impact. The employment of a mold surface treatment producing a surface roughness able to conceal mold transfer defects has enabled the external design requirements for the tank to be satisfied.

1. Introduction

Efforts for the reduction of automotive environmental pollution are becoming increasingly important during recent years. Requirements for environmental pollution control in motorcycles, in particular with regard to exhaust gases, are also increasing year by year. Against the background of this trend, North American exhaust emission regulations have been more stringent than those of other countries; also, the U.S. Environmental Protection Agency's (EPA) new regulations concerning gasoline exhaust emissions for 2008 year model motorcycles have been established. To change to a metal fuel tank helps eliminate fuel permeation from the tank surface. However, we set out to meet the fuel permeation regulations using a resin fuel tank, which is superior from the perspectives of lightening, corrosion resistance, shape flexibility, cost, and recovery from impact. Conforming to the regulations using the single-layer polyethylene (PE) resin fuel tanks employed in conventional models represents a challenge. Therefore, 4-materials and 6-layers multilayer continuous blow molding with an ethylene-vinyl alcohol copolymer (EVOH) barrier was selected considering permeability,

durability, and tank function.

Blowouts occur during blow molding of the ductile parts of saddle-shaped, highly ductile exterior fuel tanks. There is a greater decline in the temperature of the resin following extrusion of the parison when using a combination of multilayer continuous blow molding and insert molding, a characteristic method used for motorcycles and ATV, than there is when using conventional PE single-layer accumulative blow molding. This results in a reduction of the welding performance of the insert parts, which can produce fuel leaks. By contrast with single-layer PE, when the joints of the insert-molded parts receive loads during impacts, the multilayered EVOH and high-density polyethylene (HDPE) undergo delamination, producing damage which can result in fuel leaks. In addition, orange peel and die lines on the surface of the tank detract from its external appearance.

In order to address the issues indicated above, a control of the pre-blow conditions and the depressuring and exhaust conditions during blow molding, the temperature behavior of the adhering sections, the design of the adhesive strength of the adhesion layers, and the mold surface treatment were focused on in this

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development. A multilayer continuous blow molding and insert molding manufacturing method, which complied with the gasoline permeation regulations, were sought to be established, and, to satisfy functions of multilayer resin external fuel tank, the development of a high-ductility saddle-shaped fuel tank was targeted⁽¹⁾.

2. Characteristics of Off-road Motorcycle Fuel Tanks

Off-road motorcycles, which have a steel main pipe positioned in the center of the body, need saddle-shaped fuel tanks that straddle the main pipe. The difference between concavities and convexities is greater than the box-shaped fuel tanks employed in automobiles. Figure 1 shows the external appearance of a saddle-shaped motorcycle fuel tank.

Molds are available for the insert parts – the fuel filler cap, fuel cock mount, and metal nuts for mounting the tank shroud and seat. The insert parts are connected to the parison, the matrix of the tank, by adhesion. For the fuel tanks of off-road motorcycles and ATVs, which have a small clearance with the external cover, insert molding is a suitable method from the perspective of space efficiency and to help ensure sufficient volume, and presents advantages over post-welding adhesion. Figure 2 shows the layout for the insert parts of an off-road motorcycle fuel tank.

An impact load on the adhesion surfaces of the insert parts has resulted in delamination of the multilayered materials, a phenomenon that does not occur in a single-layered PE tank. This phenomenon occurs because the strength of the adhesion layer that bonds the HDPE and EVOH layers is low. The stress on the extremities of weld-molded insert parts adhering to the parison is predicted to be higher than for insert parts that are attached following molding.

In an off-road motorcycle fuel tank, the surface of the blow-molded molding is used as the exterior surface. The exterior of the fuel tank is formed by transferring the form of the surface treatment of the mold to the surface of the fuel tank. Before discussing individual technologies below, this section will provide an outline of the flow of blow



Fig. 1 Appearance of saddle-type fuel tank for motorcycle

molding procedures.

- (1) The resin raw material is heated, melted, and kneaded in the screw sections of the extrusion cylinders.
- (2) The resin extruded from the screws flows in a ring shape from the tips of the cylinders to the die head.
- (3) Ring-shaped resin flows in the same way from the cylinders used for each layer towards the die head. The ring-shaped resin materials sink downwards in tubular shapes. The resin materials adhere closely, forming a laminated tube. This high-temperature resin tube is the parison.
- (4) The parison is gradually formed lower than the die head by extrusion of resin from each of the cylinders.
- (5) The lower section of the parison is pinched to form a bag shape.
- (6) The depressuring and exhaust of the bag-shaped parison are conducted by means of the air channels in the die head.
- (7) The parison is set in the mold.
- (8) The blow pin in the mold is inserted into the parison.
- (9) Air is blown in via the inserted blow pin, and the parison is formed by pressing to the mold.
- (10) The mold is opened and the molded product is ejected⁽²⁾.

This flow is illustrated in Fig. 3.

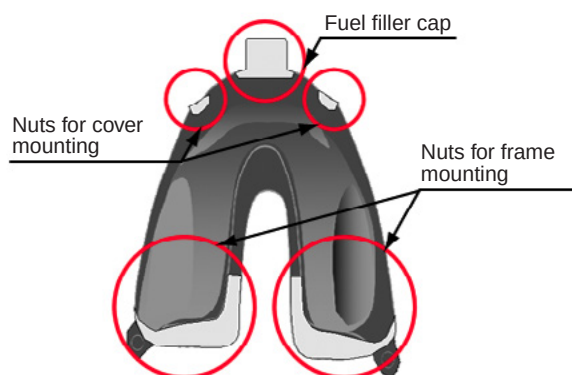


Fig. 2 Insert parts layout of fuel tank for off-road motorcycle

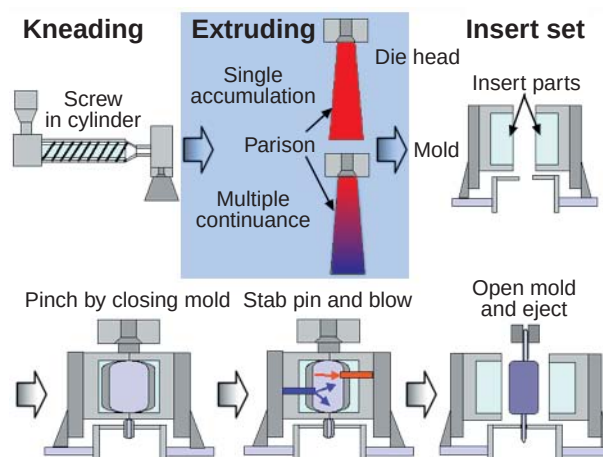


Fig. 3 Blowing process

3. Issues of Multilayer Continuous Blow-molded Motorcycle Tanks

- (1) Compared to a fuel tank for a four-wheel vehicle, highly ductile molding is needed for a saddle-shaped motorcycle fuel tank, and blowouts occur during blow molding of the ductile sections.
- (2) The decline in the temperature of the resin following extrusion of the parison is greater in the case of multilayer continuous blow molding than in conventional single-layer accumulative blow method using PE. Because of this, a decline in the adhesion performance of the insert parts may occur when using a combination of multilayer continuous blow molding and the insert molding that is used specifically for motorcycles and ATVs, and this may lead to fuel leaks.
- (3) By contrast with single-layer PE, when the joints of the insert-molded parts receive an impact load, delamination of the EVOH and HDPE that adhere in the multilayer structure occurs, producing damage, which may result in fuel leaks.
- (4) The fuel tank of a motorcycle is an external part, and it is therefore necessary to take measures to enhance the external appearance of the tank in response to orange peel and die lines.

It was necessary to develop technologies to address these characteristic motorcycle fuel tank issues.

4. Development of a High-ductility Saddle-shaped Fuel Tank

The fuel tank for off-road motorcycles should be formed into a saddle shape with large concavities and convexities. Figure 4 compares the forming ductility of a saddle-shape motorcycle tank with that of a four-wheel vehicle tank.

4.1. Pre-blow Molding

During blow molding, if the parison ejected from the

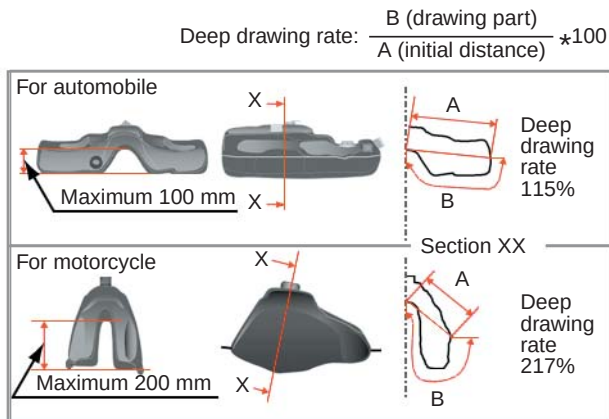


Fig. 4 Comparison of forming ductility with automobile fuel tank

molding machine die core is directly blown, the parison easily makes contact with the mold. The parison adheres to the mold, and the parison between the contact points are stretched and melted. The stretched sections between the contact points are reduced in thickness. Then, in the case of saddle-shaped tanks with large concavities and convexities, blowouts occur. Performing pre-blowing before blow molding to form the necessary tank perimeter in advance, to help ensure uniform thickness after blow molding, is an important molding method. If this method is not used, it is not possible to mold a high-ductility saddle-shape tank. Figure 5 shows the behavior of the parison during pre-blowing.

If the pre-blowing time is too short, blowouts will occur from the thin sections of the parison during blowing; if the pre-blowing time is too long, blowouts will occur during pre-blowing. The setting of pre-blowing conditions is important from the perspective of achieving a uniform wall thickness.

For the formation of the saddle-shape fuel tank discussed in this paper, setting a pre-blowing time of 0.4 sec resulted in a more uniform wall thickness. Figure 6 shows the relationship between the pre-blowing time and the minimum wall thickness of the product.

4.2. Depressuring and Exhaust Molding

The depressuring and exhaust process is even more important than pre-blowing in terms of achieving a uniform wall thickness. If the depressuring and exhaust process is not conducted, after mold closure, the pre-blown parison will contact the surface of the mold, in addition to which the mold will bite the parison in areas other than the predetermined areas, which can result in thin walls in the molding. Depressurizing the pre-blown parison produces sagging in the radial direction, enabling the outermost external radius of the parison to be compressed without change, relative to the actual perimeter of the parison, helping to prevent unwanted biting of the parison by the mold and enabling maximal

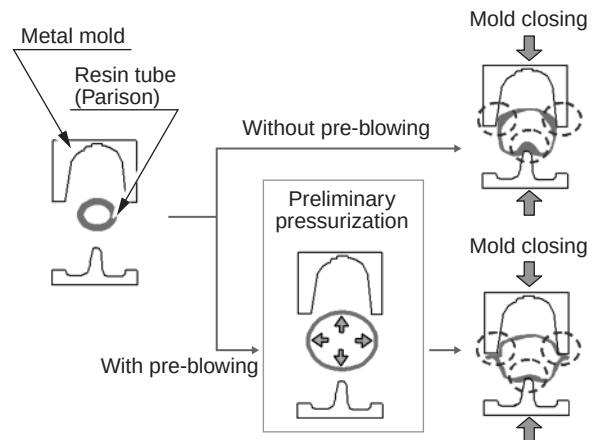


Fig. 5 Behavior of parison during pre-blowing

use of its perimeter. When depressuring and exhaust continues, adherence occurs in the interior of the parison, and the parison cannot be blow molded.

In the case of the saddle-shape fuel tank discussed in

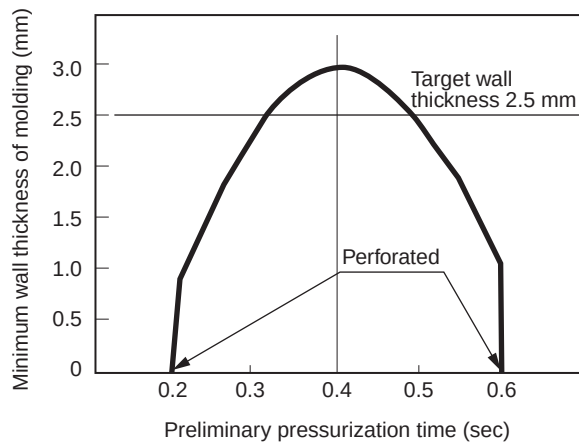


Fig. 6 Relationship between preliminary pressurization time and minimum wall thickness of molding

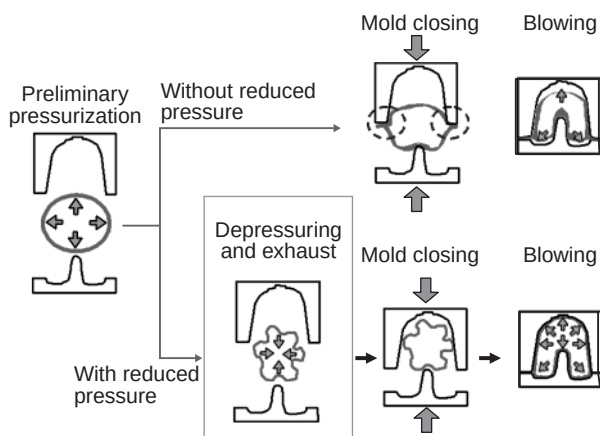


Fig. 7 Behavior of parison during depressuring and exhaust

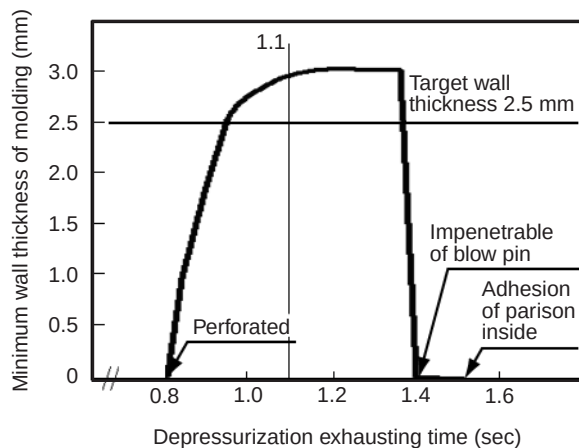


Fig. 8 Relation between depressurization exhaust and minimum thickness of molding

this paper, a depressuring and exhaust time of 1.1 sec was set, balancing contact with the mold, avoidance of unnecessary biting, and adhesion resistance in the interior of the parison, enabling the achievement of a more uniform wall thickness. Figure 7 shows the behavior of the parison during the depressuring and exhaust process. Figure 8 shows the relationship between depressuring and exhaust time and the minimum wall thickness of the product.

5. Achievement of Insert Parts Adhesion Performance

5.1. Parison Temperature

The insert parts adhere to the parison, which forms the body of the fuel tank. The adhesion performance of the insert parts is important, because fuel leaks can result in particular from adhesion imperfections in the fuel filler cap and fuel cock mount. Conventional single-layer PE tanks are molded by accumulative blowing. In this method, resin is accumulated in the molding machine. Immediately prior to molding, the parison is extruded and blow-molded in a mold in which the resin insert parts, having been preheated in an oven, have been set, enabling the insert parts and the parison to adhere. The time that elapses following extrusion of the parison is short, enabling the achievement of good adhesion with the insert parts.

In the multilayer continuous blow molding method, by contrast, no resin is accumulated in the molding machine and the parison is continuously extruded in order to avoid heat degradation of the EVOH. Because of this, the resin temperature is lower at the initially extruded parison tip. This is an unfavorable condition for adhesion molding of the insert parts. At the same temperature setting as used for conventional single-layer PE molding, as the temperature is insufficient when the parison and insert parts were connected, peeling would result in gasoline leaks. Increasing the parison temperature by 30 or 40 °C against the setting used in single-layer accumulative PE molding, in order to enhance adhesion performance, resulted in the phenomenon of drawdown, in which the parison breaks under its own weight and falls to the bottom. Simply setting a higher resin temperature would result in issues such as heat degradation of the parison resin and breaking of the parison due to drawdown. This meant that there was a limit to the ability to increase the resin temperature, and that a balance between temperature and adhesion would have to be sought. Increasing the temperature by 20 °C against the conventional temperature setting in an attempt to enhance adhesion performance enabled the achievement of a balance between drawdown resistance and adhesion. Figure 9 shows the temperature transition following extrusion of the parison.

5.2. Temperature of Insert Parts

Section 5.1. focused on the temperature of the parison, but it was determined that the temperature of the parison

was not the only factor in achieving adhesion of the insert parts. It was judged that it would also be necessary to consider the temperature of the insert parts. The temperature setting for the insert parts was therefore reexamined. In advance, the insert parts are preheated in a heating oven and set in the mold before blow molding, and then blow molding is conducted. The preheating temperature for the insert parts was set 30 or 40 °C higher than the temperature for conventional single-layer PE accumulative molding, and molding was attempted. This resulted in melting damage to the insert parts in the oven and deformation of the insert parts during handling following removal from the oven. The temperature of the insert parts decreases following removal from the heating oven. When the insert parts have been set in the mold, there is an even more noticeable decline in the temperature of the parts due to heat radiation into the mold. For the insert parts also, the preheating temperature setting was increased by 20 °C against the conventional temperature in order to enhance adhesion performance.

In addition, in order to enhance safety and productivity, a robot arm has been employed to set the insert parts in the mold rather than setting them manually. This increased the time required to remove the parts from

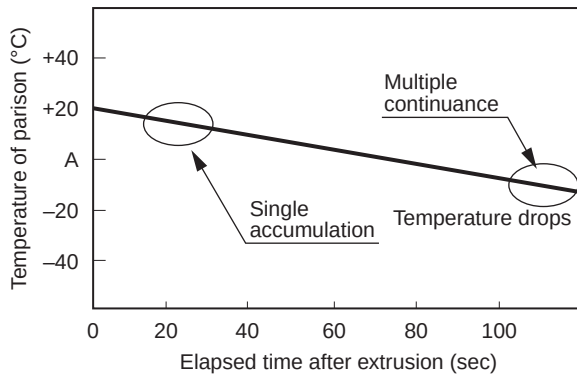


Fig. 9 Temperature transition after parison extrusion

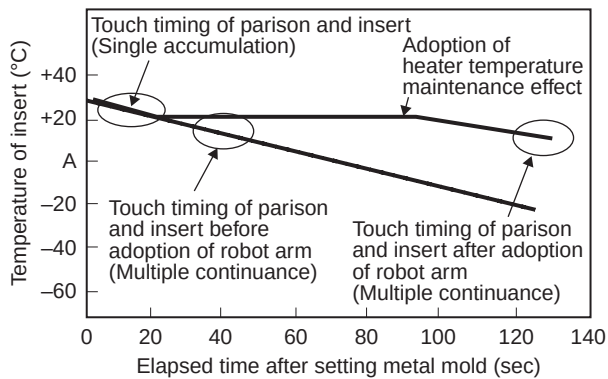


Fig. 10 Temperature transition of insert parts with thermal heater temperature maintenance effect after removal of insert parts from heating oven

the oven and set them in the mold, resulting in a decline in their temperature. In order to avoid this decline in temperature during the standby time before the robot arm grips the insert parts, a thermal heater has been added to provide concurrent heating, enabling the temperature of the adhesion surfaces to be maintained. Figure 10 shows the temperature transition of the insert parts as a result of employment of the thermal heater.

6. Design of Adhesive for Bonding Multiple Resin Layers

Achieving adhesion with PE represents a challenge, and a modified polyethylene adhesive is therefore used between EVOH and PE when bonding the two substances. The adhesive strength of the adhesive affects the strength of the fuel tank under impacts at low temperatures, and the form of damage it sustains under these impacts. A tank that contains insert parts sustains damage due to peeling of the adhesive layer originating at the lateral ends of the insert parts. This type of damage is specific to insert-molded tanks, and does not occur in the case of tanks in which the insert parts have been attached following molding. It is one aspect of insert-molded tanks that need to be considered in order to increase impact strength. Adhesives are subjected to maleic anhydride modification in order to enhance adhesion performance. Maleic

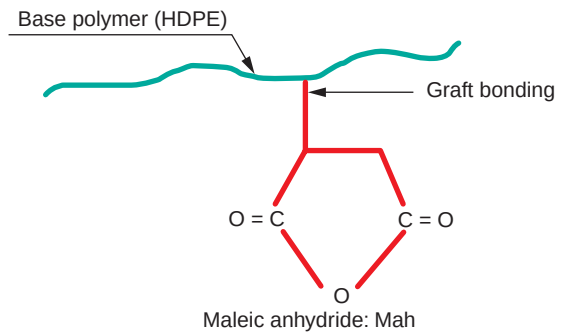


Fig. 11 Bonding structure of olefins and maleic anhydride

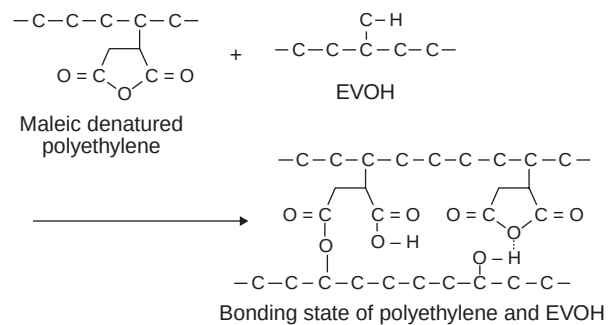


Fig. 12 Reaction mechanism of maleic anhydride and EVOH

anhydride contains a vinyl radical, and therefore reacts readily with polyolefins. Figure 11 shows the bonding structure of olefins and maleic anhydride, and Fig. 12 shows the reaction mechanism of maleic anhydride and EVOH.

The amount of maleic anhydride in the adhesive is the main factor affecting adhesive strength. Increasing the amount of maleic anhydride in the adhesive increases its adhesive strength. However, maleic anhydride is a costly substance, and it is therefore necessary to achieve a balance between adhesion performance and cost with regard to the amount of maleic anhydride used. Low-temperature impact tests were conducted on molded fuel tanks using adhesives containing 0.05, 0.1, and 0.15% maleic anhydride, as used to bond insert parts in post-molding welding. Following the tests, the tanks showed damage occurring as a result of peeling of the adhesion layer originating at the ends of the insert parts. No peeling of the adhesion layer was observed in low-temperature impact tests when adhesives containing more than 0.3% maleic anhydride were used. The percentage of maleic anhydride, an index of the amount of maleic anhydride in the adhesive, was set at 0.35, based on considerations of safety. This enabled stable adhesive strength to be

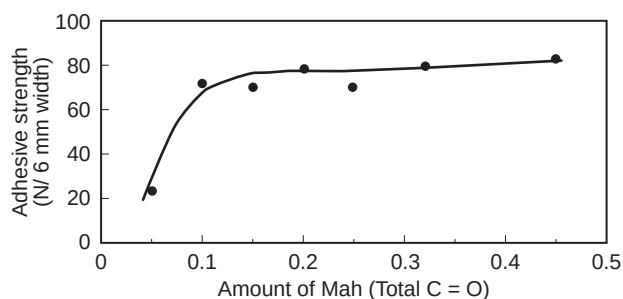


Fig. 13 Relationship between Adhesive strength and amount of maleic anhydride

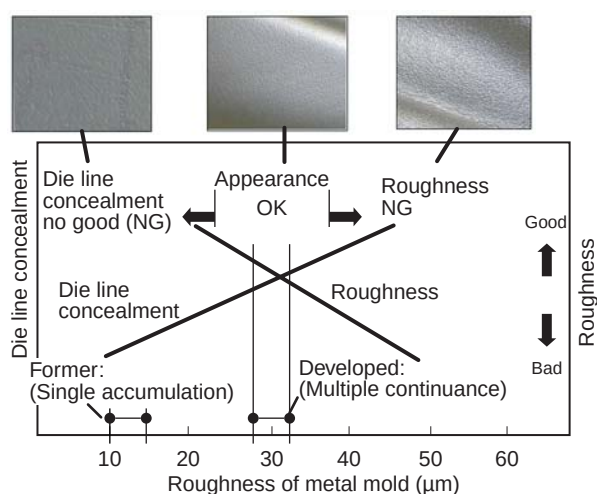


Fig. 14 Relationship between roughness and roughness of metal mold for finishing

achieved at minimum cost. Figure 13 shows the relationship between adhesive strength and the amount of maleic anhydride in the adhesive^{(3), (4)}.

7. Mold Surface Treatment for Exterior Design of Fuel Tank

Contrary to the internal fuel tanks used in four-wheel vehicles, resin fuel tanks for off-road motorcycles are colored and used as an aspect of the exterior design of the vehicle. The temperature of the resin forming the parison is lower in multilayer continuous blow molding than in PE single-layer accumulative blow molding, and mold transfer is therefore inferior when using the former method. This represents a disadvantage in terms of coloring the resin at the exterior of the tank. Shot blasting is conventionally used as a mold surface treatment, producing minute concavities and convexities of 10-20 μm . The lower parison resin temperature in multilayer continuous blow molding means that the undulations of the die lines on the surface of the parison cannot be filled by the shot-blasted concavities and convexities, and a style design therefore cannot be formed. In order to conceal the concavities and convexities on the surface of the parison, a chemical treatment was applied to produce a grained surface of a sufficient depth (30 μm) and form, enabling the exterior design requirements to be satisfied. Figure 14 shows the relationship between the external appearance requirements of the tank and the depth of the mold surface treatment.

8. Effect of Employment of Developed Fuel Tank

The developed fuel tank has been employed in the 2008 model year CRF-F and CRF-X Series off-road motorcycles and all Honda 2008 model year ATVs. This has contributed to the protection of the environment by reducing the emission of gasoline to the atmosphere substantially. In addition, the development of a manufacturing method combining multilayer continuous blow molding and insert molding has contributed to the achievement of a high level of space efficiency without modification of the layout of the covers and seat base plates employed around the fuel tanks of off-road motorcycles and ATVs. Honda intends to expand its use of the new tanks, fitting them to models falling under the purview of the U.S. EPA gasoline permeation control regulations from 2008 year models.

9. Conclusion

A fuel tank for off-road motorcycles and ATVs manufactured using a combination of multilayer continuous blow molding and insert molding has been developed. The salient points of this development project are as follows:

- (1) The setting of a pre-blow time of 0.4 sec and a depressuring and exhaust time of 1.1 sec for the molding of a high-ductility saddle-shape fuel tank of the shape discussed in this paper enabled molding with a highly uniform wall thickness.
- (2) With regard to the adhesion performance of the continuous blow-molded parts and weld-molded insert parts, raising the pre-heating temperature of the insert parts and the parison temperature by 20 °C each and employing a thermal heater for concurrent heating of the insert parts before they are set in the mold by a robot arm enabled the achievement of a balance between adhesion performance, resistance to melting damage in the insert parts, and resistance to drawdown in the parison.
- (3) The use of a maleic anhydride content of 0.35% in the adhesive employed to bond the EVOH and HDPE layers in the multilayer parison enabled the achievement of the necessary adhesive strength for impact resistance in the blow-molded and insert-molded fuel tank.
- (4) The application of a chemical surface graining treatment to the mold and a grain depth setting of 30 μm enabled the achievement of a good external appearance for an off-road motorcycle fuel tank.

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