ThreeBond
TECHNICAL NEWS

ThreeBond Technical News
Issued January 1, 2024
103

UV-curing Gasket Molding Technology for Use with Fuel Cells

Introduction

In recent times, the automotive industry has seen an accelerating shift away from fossil fuels and toward alternative forms of energy with the aim of achieving carbon neutrality. Against this backdrop, fuel cells, which do not emit substances harmful to the environment during driving, have garnered particular attention as a new power source for next-generation automobiles. Gaskets that can seal substances such as hydrogen gas and coolant fluid are indispensable in the use of fuel cells. With more varied applications and increased production as part of the progression towards the widespread adoption of fuel cells, there is also a need for gasket molding processes that reduce production takt times in order to enhance design freedom and reduce costs.

Conventional sealing methods include the UV-cured-in-place gasket (UV-CIPG) method, which uses UV-curable gaskets that are applied and cured with UV light before assembly takes place. These gaskets are described in ThreeBond Technical News No. 72. However, disadvantages of this method include the high level of production technology required to achieve consistent gasket dimensions and the fact that there are restrictions on the cross-sectional shapes into which gaskets can be molded.

In this article, the authors describe the light-curing mold method, a new molding technology that resolves issues faced with conventional methods, and ThreeBond 3178B, a UV-curing gasket that provides the performance required for fuel cell-related applications. These innovative molding technologies can be expected to make a major contribution to the widespread adoption of fuel cells and the establishment of a sustainable automotive industry.

Hereafter, ThreeBond is abbreviated as TB.

Table of Contents

1. Overview of FCEVs and Gasket Requirements

1-1. FCEVs

Unlike automobiles with conventional engines, fuel cell electric vehicles (FCEVs) are a type of automobile that run using motors powered by electricity produced using hydrogen and oxygen as fuel.

Against the backdrop of the sustainable development goals (SDGs) and other international initiatives aimed at resolving social issues and building a sustainable future, FCEVs' qualities as vehicles that only emit water and do not emit CO_2 during driving mean they can be expected to contribute to efforts to address climate change and other environmental issues by enabling the realization of decarbonization.

1-2. Electricity Generation in FCEVs

Fuel cells generate electricity through a mechanism comprising hydrogen, oxygen and cell stacks. As shown in Figure 1, cell stacks are stacks consisting of hundreds of cells. These cells consist of three layers—an electrolyte membrane and two electrode plates (positive and negative). They generate electricity through the chemical reaction between hydrogen and oxygen.

1-3. Gasket Performance Requirements

When fuel cells generate electricity through the chemical reaction between oxygen and hydrogen, oxygen, hydrogen and coolant flow between the cells. The coolant reduces the heat produced during electricity generation. The gaskets between cells must have effective barrier qualities. One reason for this is that hydrogen, in particular, has a low molecular mass and can leak through even the slightest gap. As a colorless and odorless flammable gas, when it mixes with oxygen in the air, even small sparks can result in fires.

Furthermore, because hundreds of cells are stacked together, the gasket dimensions must be precise and gaskets require effective sealing properties that can adapt to the expansion and contraction caused by the heat produced during electricity generation.

In order to withstand the chemical reactions and temperature changes that take place inside cell stacks, gaskets must also have the durability to maintain a stable barrier under low-temperature, high-temperature and high-pressure conditions. These gaskets are compressed while being exposed to high temperatures, and must maintain their repulsive force without failing.

Issues faced with conventional technologies using thermoplastic resin include the significant thermal effect on cells when insert molding is used to apply the gaskets and long processing times due to time needed for heating and cooling.

To resolve these issues, ThreeBond began development of UV-curing gaskets and related molding methods that meet the performance requirements for fuel cell-related applications while using energy from UV light to enable immediate curing at room temperature under normal atmospheric pressure.

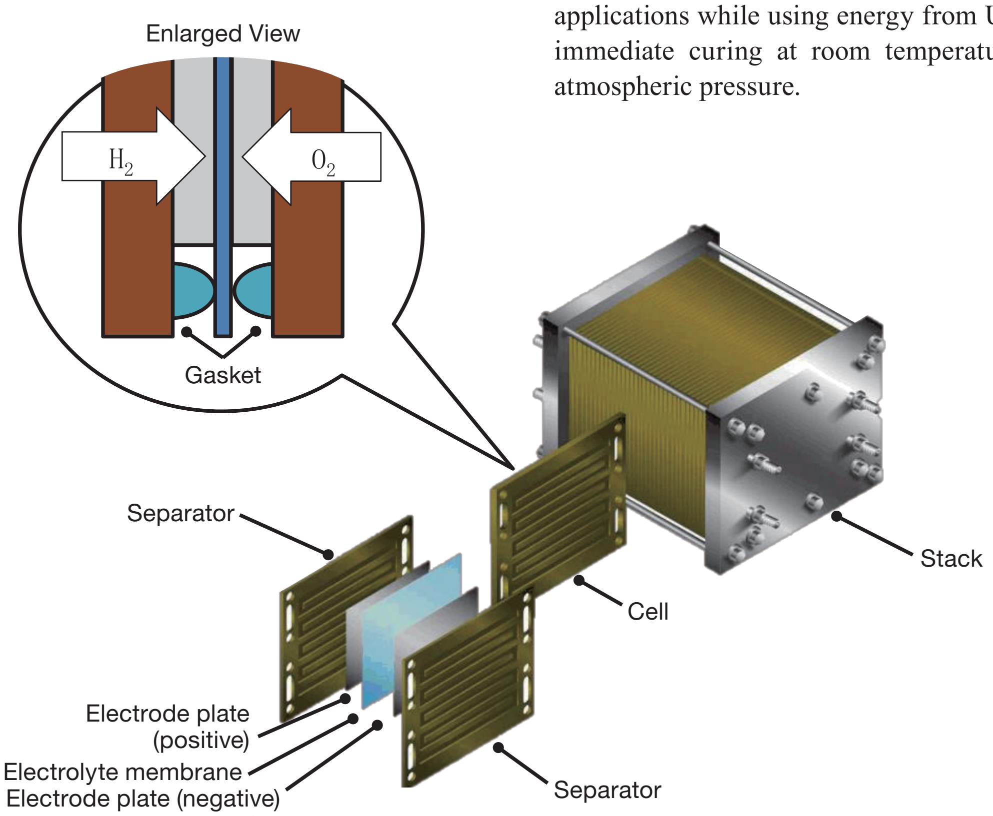


Fig. 1 Cell Stack Composition

2. Molding Methods for Use with FCEVs

2-1. Conventional Molding Methods and Related Issues

In general, when thermoplastic resin is molded to cells, insert molding with a die is used to perform integral molding on the cell and gasket.

As mentioned earlier in this article, ThreeBond has also put forward the UV-CIPG method. With the UV-CIPG method, simple equipment comprising an applicator and dispenser is used to apply UV-curing sealant to the seal surface. The gasket is then molded through irradiation with UV light.

A comparison of the two methods is shown in Table 1.

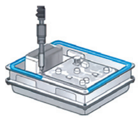
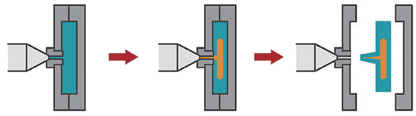
These conventional methods for molding gaskets to cells presented issues in terms of production cost, quality and processing times.

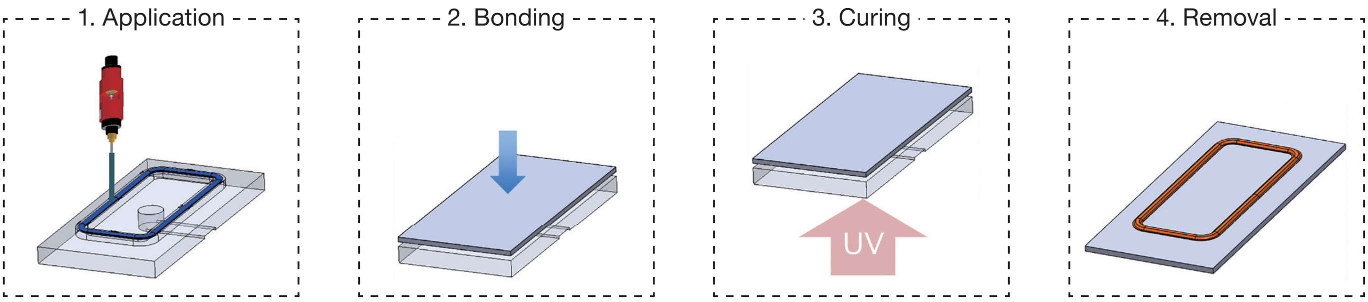
2-2. New Molding Methods

With the aim of resolving the issues found with conventional methods, ThreeBond developed the **light-curing molding**, which combines the simplicity of the UV-CIPG method with high gasket dimension precision similar to the insert molding method.

With this method, the gasket is molded using a transparent shaping die with grooves in the required gasket shape. An overview of the light-curing mold method is shown in Figure 2.

Table 1 Comparison of Conventional Methods

Method	UV-CIPG	Standard insert molding
Illustration		
Dimension precision	**Average** Difficult to manage start and end point dimensions	**Excellent** High precision (mold shape is reproduced accurately)
Equipment costs	**Excellent** Low cost (simple equipment configuration)	**Inadequate** High cost (die, injection equipment and heat source required)
Running costs	**Excellent** Low cost (cures immediately with UV light)	**Inadequate** High cost due to heat energy
Suitability for mass production	**Average** Robot adjustment required for every environmental change	**Good** Mold shape is reproduced, reducing variation during production
Freedom to change design	**Excellent** Changes to applicator setup only	**Inadequate** Redesign from prototype die
Gasket shape freedom	**Inadequate** Dependent on liquid properties of sealant	**Excellent** Even complex shapes are possible



UV-curing gasket is dispensed into grooves in the shaping die.

The workpiece and the shaping die to which the gasket was applied are bonded together.

The gasket is cured through irradiation with UV light from UV-LEDs.

When the shaping die and workpiece are torn away from each other, a gasket of the desired shape is molded to the workpiece.

Fig. 2 Light-curing Mold Method Overview

2-3. Benefits of Light-curing Mold Method

Shaping dies similar to the example shown in Figure 3 are used. Gaskets accurately reproduce the shape of the grooves, making it easy to achieve high dimension precision.

Additional benefits are as follows.

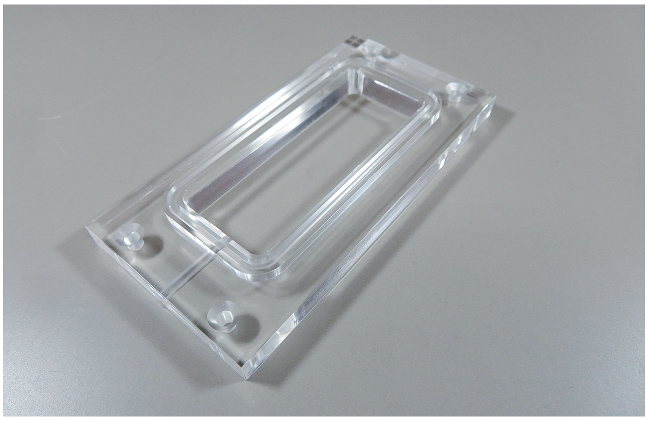


Fig. 3 Shaping Die

1. Improved process capabilities

With the UV-CIPG method, the gasket retains the same shape it had when it was applied by the dispenser. To prevent changes in shape due to the sealant's flowability or wettability on the workpiece, the sealant must have high viscosity and thixotropicity immediately after application. Robots must also move slowly (approximately 30 mm/s) in order to create moldings with uniform shapes, limiting the processing time efficiencies that can be achieved.

With the light-curing mold method, by contrast, a low-viscosity, low-thixotropicity UV-curing gasket is used to facilitate flow into the mold grooves, enabling robots to move at higher speeds (approximately 150 mm/s).

2. Reduced load on gasket

During insert molding with thermoplastic resins, when the resin flows into the channels, an orientation effect that stretches the polymer molecules in the direction of flow occurs at the boundaries between the still-molten resin and the cool, solidified resin layer and the inner surface of the shaping die. Sheer stress can also occur between the flowing layer and the solidified layer, meaning that the tensile and bending strengths of molded items may differ in the direction of flow and the vertical direction.

With the light-curing mold method, because the UV-curing gasket is cured immediately with energy from UV light, flowing and solidified layers do not form and this orientation effect does not occur. Gaskets with uniform strength can therefore be molded.

3. Reduced load on workpiece

With insert molding, because heating and cooling form part of the process, the thermal load on the workpiece is unavoidable. In addition, because high-pressure injection is necessary to ensure that resin does not leave small gaps when flowing into the die, a strong tightening force between the die and the workpiece is required.

With the light-curing mold method, however, because the die and workpiece are pasted together after application, a strong tightening force is not required. This reduces the load during molding.

4. Simplification of processing conditions

Setting the molding conditions is an important aspect of insert molding. Several parameters must be considered, including the temperature of the melted resin and die, the injection speed and the pressure. These conditions are set based on experience and fluid analysis, and the process is time and labor intensive. For the resin to flow efficiently through the channels, heating-induced changes in resin viscosity and changes in temperature during injection must be calculated. The injection speed and pressure also affect the temperature, which further complicates the calculation conditions, increasing the time needed to ascertain the optimal conditions.

The shaping die must also be designed with precision. The position and number of inlets and outlets are important factors in ensuring that resin flows into the entirety of the channels. Design work and repeated prototyping based on experience and fluid analysis take time and increase costs.

In addition, experience and highly-accurate analysis are required to reduce stress in the molded object caused by orientation effects.

With the light-curing mold method, application is performed using grooves in a transparent shaping die, which means that the complex fluid flow calculations required for insert molding can be omitted and the mold can have a simpler structure. As a result, managing the amount of discharge from the dispenser is sufficient when setting the conditions.

In addition, because molding is performed under normal atmospheric pressure and at room temperature, quantitative conditions can be set using sensors during the bonding and removal processes, making process management even easier. Through these characteristics, this method simplifies processing conditions.

3. TB3178B: UV-curing Gasket

3-1. Features

TB3178B is a polyisobutylene-based non-solvent UV-curing gasket. Its characteristics are described below.

(1) Curable in a short time with irradiation with light wavelengths from UV to visible light (wavelengths of 200 to 405 nm)

(2) Excellent hydrogen gas and humidity barrier properties

(3) Rubber elasticity maintained over a wide temperature range (-40°C to 120°C)

(4) Small compression set and excellent sealing properties

(5) Excellent chemical resistance

3-2. Properties and Characteristic Values

The properties and characteristic values of TB3178B are shown in Table 2. To ensure suitability for the light-curing mold method, the viscosity and thixotropicity (structural viscosity ratio) have been adjusted such that the product flows easily into grooves during application.

3-3. Barrier Properties

The barrier properties of TB3178B are shown in Table 3. Polyisobutylene, which is the main component of TB3178B, has a C-C chain in its backbone, and the distance between molecules is shorter than with the siloxane chains found in silicone. Due to its low free volume, it is flexible yet has excellent hydrogen gas and moisture barrier properties.

Table 3 Barrier Properties Comparison (TB3178B and Silicone Resin)

Test item	Unit	TB3178B	Silicone resin
Hydrogen gas permeability factor	mol·m/(m²·s·Pa)	8.6×10^{-15}	1.8×10^{-13}
Moisture permeability	g·mm/(m²·24h)	80.5	545.8

Hydrogen gas permeability - Test conditions: 23°C, t = 1.0 mm
Moisture permeability - Test conditions: 85°C x 85%RH, t = 1.0 mm

3-4. Rubber Elasticity

A dynamic mechanical analysis (DMA) and the temperature retraction (TR) of TB3178B are shown in Figures 4 and 5 respectively.

TB3178B has a glass transition temperature of -43°C and can retain rubber elasticity even in low temperature bands of approximately -40°C.

3-5. Compression Set

The compression set of TB3178B is shown in Figure 6. Compression sets are used to evaluate the distortion of a gasket after durability testing. If the strain increases, the repulsive force during compression decreases, making it difficult for sealing properties to be maintained. TB3178B has a small compression set, meaning it can maintain its sealing properties for a long time.

Table 2 TB3178B Properties and Characteristic Values

	Test item	Unit	TB3178B	Testing Method	Remarks
Property	Appearance (color)	–	White	3TS-2100-020	–
	Viscosity	Pa·s	45	3TS-4200-001	25°C, shear rate: 1.0 (s^{-1})
	Structural viscosity ratio	–	1.9	3TS-4200-001	25°C, shear rate: 10 (s^{-1})/1.0 (s^{-1})
	Specific gravity	–	1.00	3TS-2500-002	25°C, liquid specific gravity
Characteristic value	Hardness	–	40	3TS-2B00-010	Durometer A
	Tensile strength	MPa	2.4	3TS-4190-001	No. 3 dumbbell
	Elongation	%	380	3TS-4190-001	No. 3 dumbbell
	Thick film curability	mm	6.2	3TS-3160-001	ø32mm
	Storage modulus	Pa	4.9×10^{6}	3TS-4730-001	1 Hz, 25°C
	Glass transition temperature	°C	-43	3TS-4730-001	1 Hz, tanδ peak value
	Hydrogen gas permeability factor	mol·m/(m²·s·Pa)	8.6×10^{-15}	JIS K7126-1	23°C
	Moisture permeability	g·mm/(m²·24h)	80.5	JIS K7129-2	85°C × 85%RH

⋆Curing conditions: 405 nm LED, illuminance: 500 mW/cm², UV dose: 40 kJ/m²

3-6. Chemical Resistance

The chemical resistance of TB3178B is shown in Figures 7 to 10. Solid polymer fuel cells fitted to items such as automobiles have operating temperatures of 70°C to 120°C, and contact between sulfonic acid groups from the solid polymer membrane and water vapor generated during operation result in an acidic environment. Consequently, fuel cell gaskets require heat resistance, water resistance, coolant resistance, and acid resistance.

Under these conditions, TB3178B can maintain stable rubber characteristics for a long time.

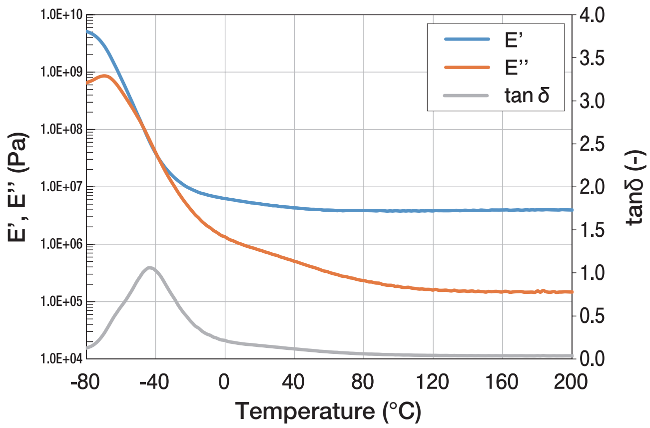


Fig. 4 TB3178B DMA

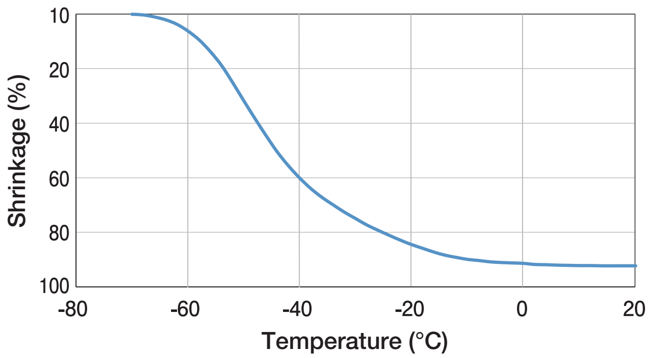


Fig. 5 TB3178B TR

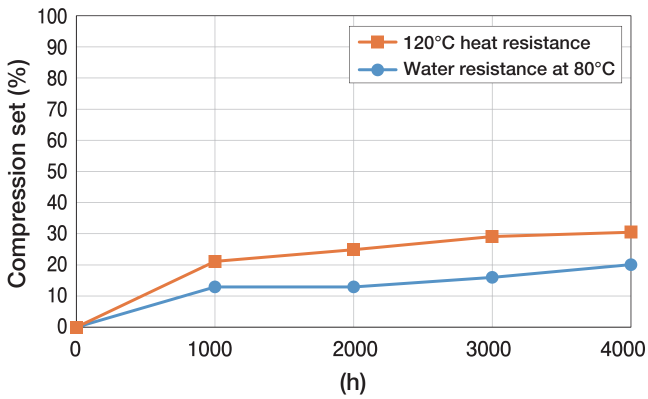


Fig. 6 TB3178B Compression Set

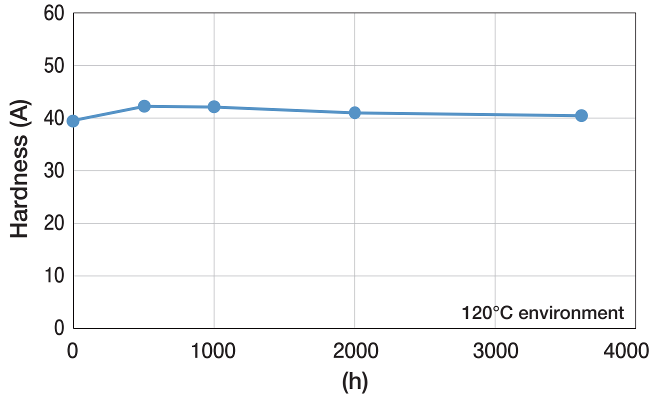


Fig. 7 Heat Resistance (Hardness)

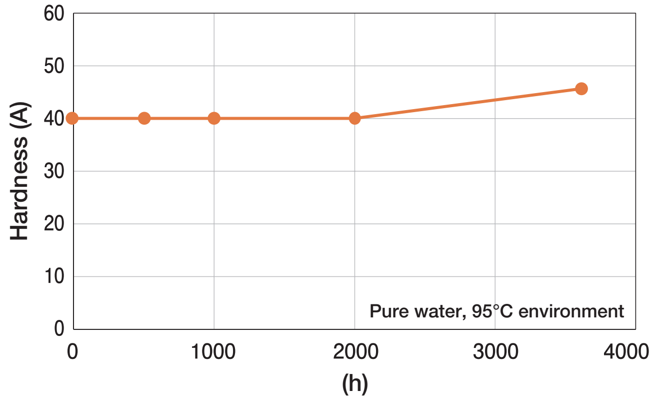


Fig. 8. Water Resistance (Hardness)

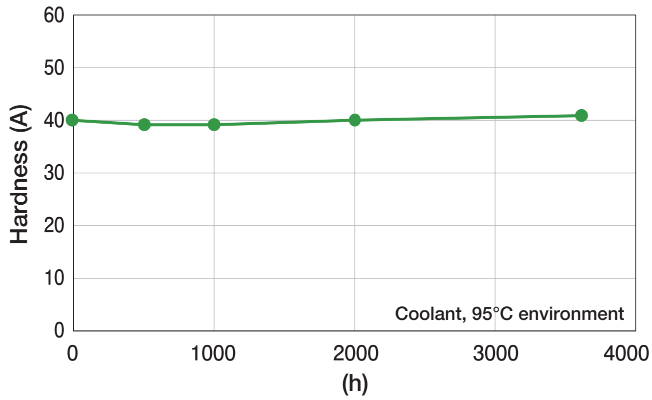


Fig. 9 Coolant Resistance (Hardness)

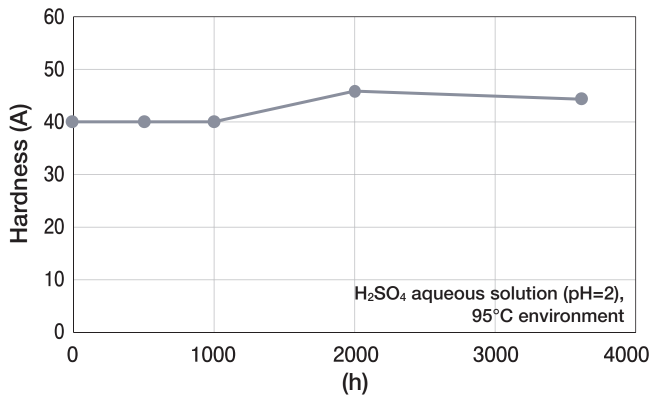


Fig. 10 Acid Resistance (Hardness)

4. Performance Improvement due to Gasket Shape

The cross-sectional shape of gaskets molded with the UV-CIPG method are dependent on the fluid characteristics of the gasket, wettability with the workpiece and dispenser performance. Differences in the cross-sectional shape of gaskets can lead to changes in performance. The light-curing mold method enables the molding of gaskets with a consistent shape and optimization of the cross-sectional shape, making it possible to stabilize and improve performance.

Accordingly, the next section describes the sealing characteristics of four typical cross-sectional shapes at low compression.

4-1. Sealing Properties: Test Method

- Gasket: TB3178B
- Test temperature: 25°C; 50%RH
- Adherend: A5052
- Seal surface: A5052
- Gasket compression ratio: 20% compression
- Curing conditions: 405 nm LED conveyor, 40 kJ/m^2
- Pressure medium: Dry air (maximum: 800 kPa)
- Pressurizing conditions: 50 kPa/30 s
- Leak threshold: Air leak of 15 mL or more in 1 sec
- Data: Median (n= 3)

Gasket for evaluation　　Flange after completion

Fig. 11 Flange for Sealing Property Test

4-2. Sealing Properties: Evaluation Content

- Cross-sectional shape of gasket under evaluation (Figure 12)
- Groove shape: 65 mm square, four corners of R10 (Figure 13)

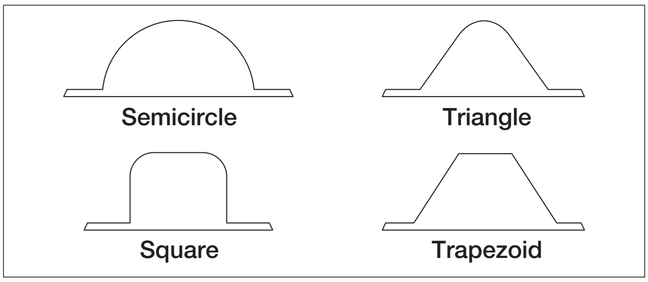


Fig. 12 Cross-sectional Shape of Gasket (Height: 1mm)

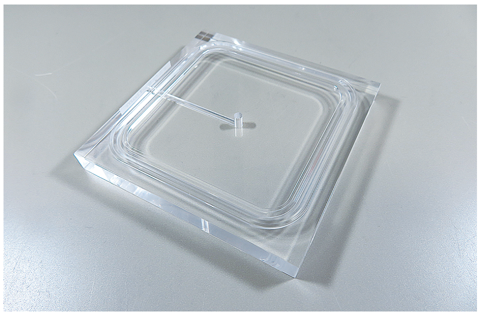


Fig. 13 Shaping Die Used for Evaluation

4-3. Results

The sealing properties of each cross-sectional shape at 20% compression are shown in Figure 14. A two-fold difference depending on the cross-sectional shape was observed. This is due to differences in the repulsive force during compression and the contact area with the seal interface. In compression seals, higher repulsive forces generally mean a higher sealing pressure. Based on the results of the cross-sectional shapes that were evaluated, it was found that increasing the repulsive force under low compression conditions and expanding the contact area were effective in improving sealing properties.

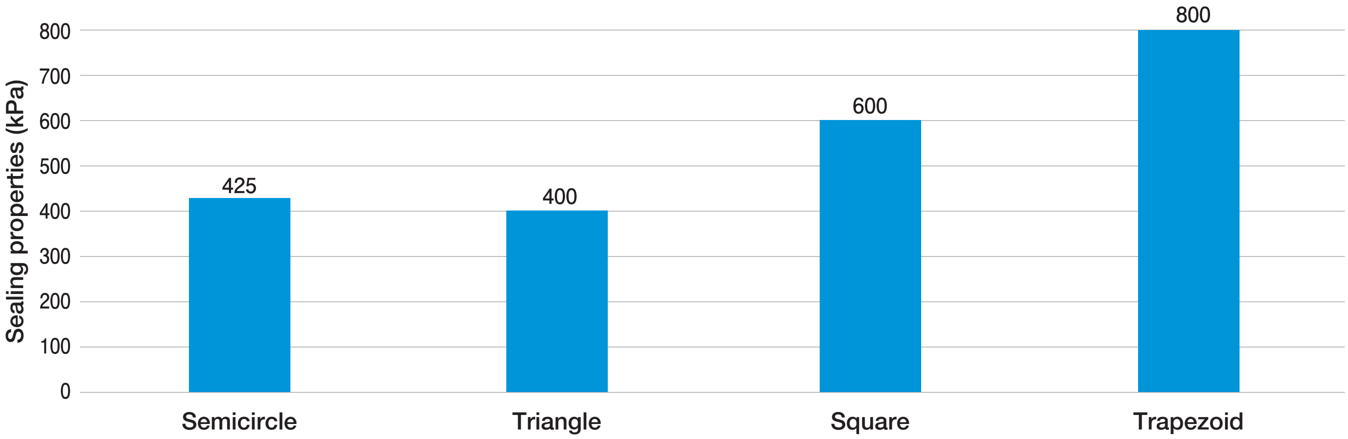


Fig. 14 Sealing Properties by Cross-sectional Shape at 20% Compression

Closing

TB3178B's characteristics make it suitable for the harsh environments found inside fuel cells, and the light-curing mold method is a flexible method combining the features of the UV-CIPG and insert molding methods. As a result, these technologies have the potential for widespread applications.

ThreeBond will continue to contribute to industrial development by focusing on further product and technology development that goes beyond existing technologies.

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