

## Heat-Curable Expanding Adhesive Sheet

### Introduction

Since our founding, ThreeBond has been hard at work developing a wide variety of liquid adhesives and sealants. Currently, we are utilizing the liquid materials we have cultivated so far and applying them to new technology to continue the development of functional sheets. This approach is about more than simply creating a sheet out of liquid materials—it is about developing a more practical adhesive by giving sheets additional functionality while utilizing the best features of both liquid and sheet adhesives. As our first step in this endeavor, we are pleased to introduce the ThreeBond 1652 heat-curable expanding adhesive sheet, an adhesive fixing sheet for motor-driven automobile motors.

Hereafter, ThreeBond is abbreviated as TB.

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## 1. Background

In recent years, conversion to petroleum substitutes and reduction of carbon dioxide (CO<sub>2</sub>) emissions have been required of the automobile industry in the effort to prevent global warming. This has spurred remarkable technological innovations in hybrid, electric and fuel cell vehicles. And, as more electronics are added to vehicles, preparations are underway to change the vehicle drive system from an gasoline/diesel powered engine to a hybrid or full electrical powered motor.

Conventionally, there are many kinds of automobile motors, and a variety of adhesives as well as liquids. For these materials such as epoxy and liquid adhesives have been the main adhesives. However, the structure of an electrical motor drive system is different from a conventional motor, so it is difficult to adapt conventional liquid adhesives for such use. For this reason, we have had to develop materials that meet this different requirements.

## 2. Development Background of the Heat-Curable Expanding Adhesive Sheet

For the IPM (Interior Permanent Magnet) motors adopted for many motor-driven vehicles, adhesive is used to affix the laminated silicon steel plate and permanent magnet (neodymium magnet) that make up the rotor.

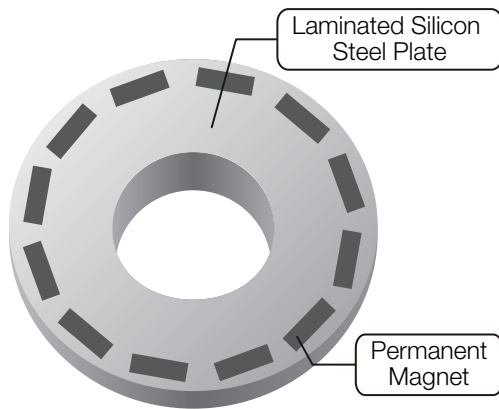


Fig. 1 IPM Motor Rotor

However, it is difficult to control the amount of liquid adhesive applied when bonding the laminated silicon steel plate and permanent magnet. The laminated silicon steel plate is a caulked structure of overlapping plates so there are gaps between the steel plates. When it hardens, capillarity causes the filled in liquid adhesive to penetrate between these layers of laminated silicon steel plates. This means that the required amount of liquid adhesive does not remain to the surface of the permanent magnet, and applied adhesive coat is uneven (Fig. 2, 3).

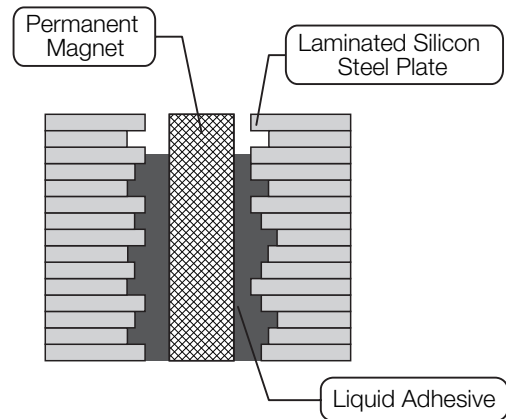


Fig. 2 Liquid Adhesive applied to a Laminated Silicon Steel Plate (Slot)

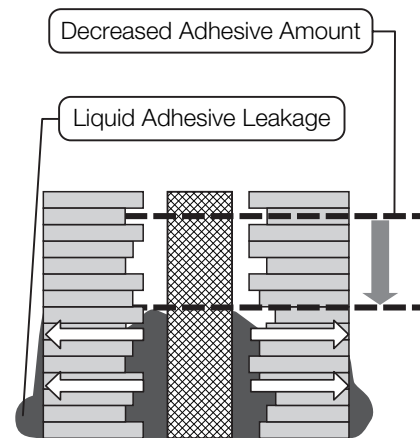
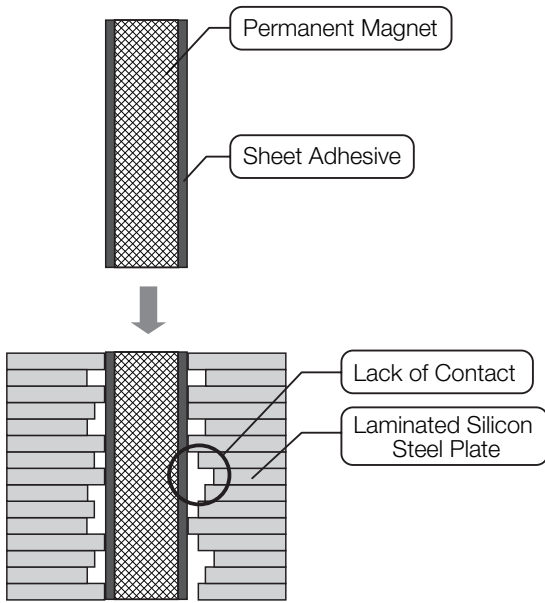


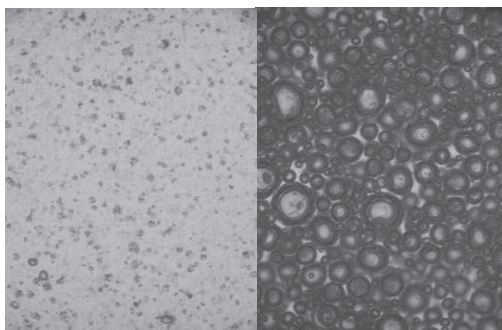
Fig. 3 Liquid Adhesive Leaking from a Laminated Silicon Steel Plate (Slot)

To solve this issue, we have approached it using a sheet adhesive. Sheet adhesives are solid at room temperature, so they can be cut to the needed size and applied on the surface of the permanent magnet, keeping the thickness and area of the adhesive constant. This makes it possible to greatly improve issues of coating unevenness common in liquid adhesives. However, in order to insert the permanent magnet into the slot in the laminated silicon steel plate, the dimensions (volume/thickness) of the adhesive layer must be smaller than the slot. Sheet adhesive dimensions alter less than liquid adhesive, with thickness and shape changing very little. As a result, conventional sheet type adhesives do not make sufficient contact with the laminated silicon steel plate, so sufficient adhesive strength cannot be maintained (Fig. 4).

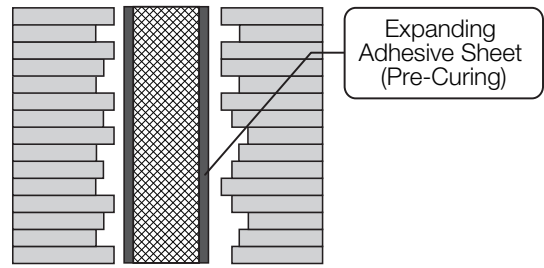


**Fig. 4 Attaching Laminated Silicon Steel Plate with Sheet Adhesive**

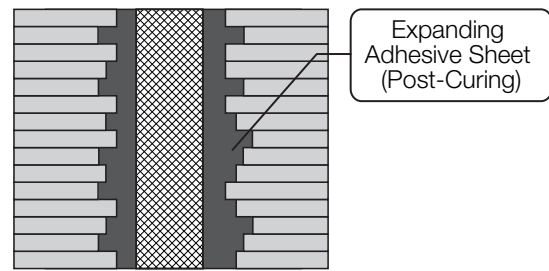
In order to fill the gaps between the laminated silicon steel plate and the permanent magnet after insertion, we combined the sheet adhesive with capsules that expand when heat is applied. The capsules expand just before the curing reaction to increase the thickness of the sheet adhesive, which changes adhesive volume (Fig. 5). Thanks to this expansion function, we succeeded in creating a heat-curable expanding adhesive sheet. This new addition to the market has added functionality that allows it to fill in gaps as it is applied and fixed (Fig. 6, 7) This heat-curable expanding adhesive sheet (hereafter abbreviated to expanding adhesive sheet) is mainly composed of a heat and chemical-resistant epoxy resin with strong adhesion to multiple materials (Table 1, 2).



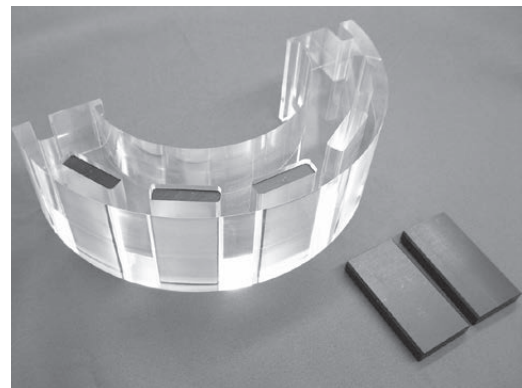
**Fig. 5 Left: Expanding Capsules Spread Throughout the Sheet  
Right: Capsules After the Sheet has Expanded**



**Fig. 6 Permanent Magnet Applied with the Expanding Adhesive Sheet and Inserted into the Laminated Silicon Steel Plate**



**Fig. 7 Heat is Applied, and the Sheet Expands to Bond and Fix the Laminated Silicon Steel Plate and the Permanent Magnet**



**Fig. 8 Mock Workpiece Bonded with the Expanding Adhesive Sheet**

### 3. Expanding Adhesive Sheet TB1652

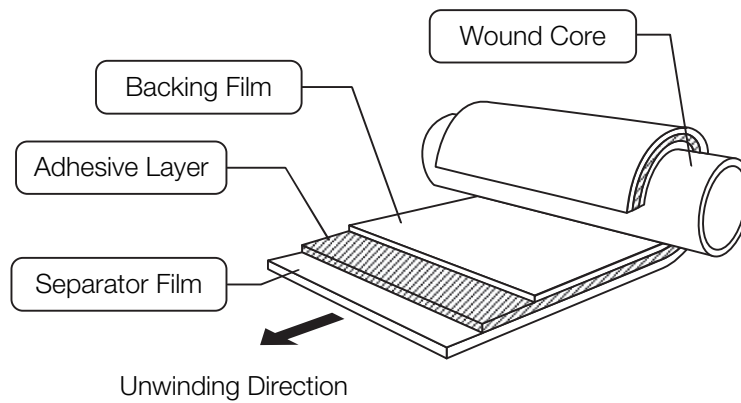
#### 3-1 Expanding Adhesive Sheet Features

- At room temperature it is a sheet-shaped solid for excellent handling and workability.
- Sheet-type adhesive can be cut to the needed dimensions prior to mounting.
- Can be inserted into gaps and affixed to simplify the bonding process.
- Heat and chemical-resistant to ensure incredible reliability.

### 3-2 Properties

**Table 1 TB1652 Properties**

|                      | Unit | TB1652      | Testing Method | Remark(s)     |
|----------------------|------|-------------|----------------|---------------|
| Appearance           | -    | White       | 3TS-201-92     |               |
| Sheet Film Thickness | μm   | 40          | 3TS-261-01     |               |
| Heat Loss            | %    | 2.0 or less | 3TS-216-01     | 80°C x 30min. |



**Fig. 9 Structure**

### 3-3 Basic Characteristics

**Table 2 Basic TB1652 Characteristics**

|                              | Unit  | TB1652               | Testing Method | Remarks  |
|------------------------------|-------|----------------------|----------------|--|
| Tensile Shear Bond Strength  | MPa   | 11                   | 3TS-301-21     | Fe/Fe  |
|                              |       | 2.4                  |                | PPS/PPS (Contains 40% glass powder)  |
|                              |       | 3.0                  |                | PBT/PBT (Contains 30% glass powder)  |
| Interlocking Bond Strength   | MPa   | 39                   | 3TS-305-01     | Stainless steel 304 pin, collar (adhesive area φ6×15mm, clearance 1/10mm)                |
| Glass Transition Temperature | °C    | 165                  | 3TS-504-01     | DMA (Dynamic Mechanical Analysis) E'' peak top, frequency: 1Hz                           |
| Storage Modulus              | Pa    | 2.8×10 <sup>8</sup>  | 3TS-504-01     | DMA E' 25°C when the expanding adhesive sheet is expanded by 4 times, frequency: 1Hz     |
| Surface Resistivity          | Ω     | 3.0×10 <sup>16</sup> | 3TS-402-01     |  |
| Volume Resistivity           | Ω·m   | 4.8×10 <sup>15</sup> | 3TS-401-01     |  |
| Expansion Scale              | Times | 4                    | 3TS-261-01     | Expansion scale when in an open state and the temperature is rising at 5°C/min. to cure. |

\*Curing conditions: 150°C×30min.

\*Tensile shear adhesive strength test piece: t2.0×25×100mm, clearance 50μm, sheet film thickness 40μm

### 3-4 Curing Time

A temperature of 150°C or more is required to cure the expanding adhesive sheet. Curing speeds at various temperatures were calculated based on DSC (differential scanning calorimetry) thermal analyzer measurement results (Fig. 10). (The standard curing conditions are 150°C×30min. for the expanding adhesive sheet)

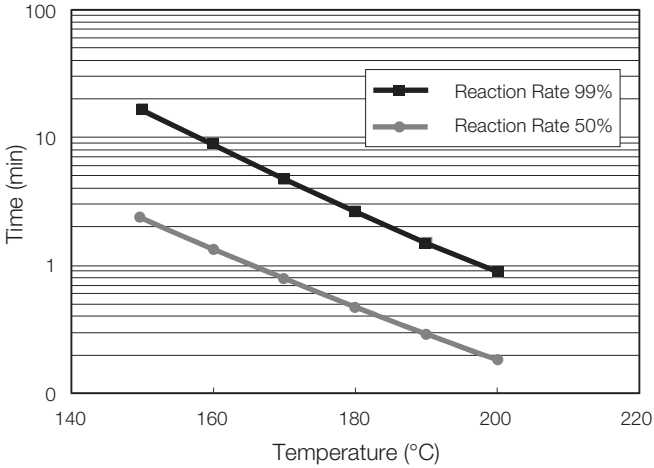


Fig. 10 DSC Reaction Rate Measurement

### 3-5 Relationship Between Clearance and Interlocking Bonding Strength

As the clearance of the expanding adhesive sheet widens with respect to the sheet film thickness, the scale of expansion increases so material and interlocking adhesive strength both decrease (Fig. 11)

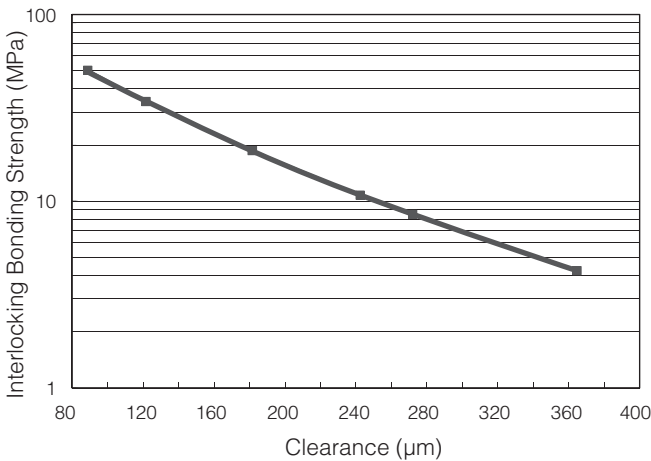


Fig. 11 Relationship Between TB1652 Clearance and Interlocking Bonding Strength

- \*Measurement method: 3TS-305-01
- \*Curing conditions: 150°C×30min.
- \*Test piece: Stainless steel 304 pin, collar (adhesive area φ6×15mm, sheet film thickness 40µm)

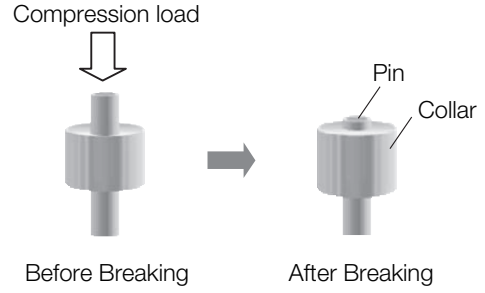


Fig. 12 Interlocking Bonding Strength Measurement Method

Measurement of breaking load by applying compression load to pins

## 4. Adhesive Characteristics

### 4-1 Interlocking Bonding Strength Comparison

We compared the interlocking bonding strength of the expanding adhesive sheet and typical liquid epoxy resins. The results of this comparison indicated that heat-curable one-part epoxy resin demonstrated the highest adhesive strength. However, when applying heat to cure, the epoxy resin runs, making the adhesive area unstable which causes the adhesive strength to vary with each measurement. On the other hand, two-part epoxy resin can be cured at room temperature, which makes the adhesive area stable, but low in strength. Though the maximum adhesive strength of the expanding adhesive sheet is inferior to that of a one-part epoxy resin, stability in the gaps in the adhesive surface increases overall adhesive strength and ensures stability (Fig. 13). (For the measurement results, the test number n=3, each result is indicated.)

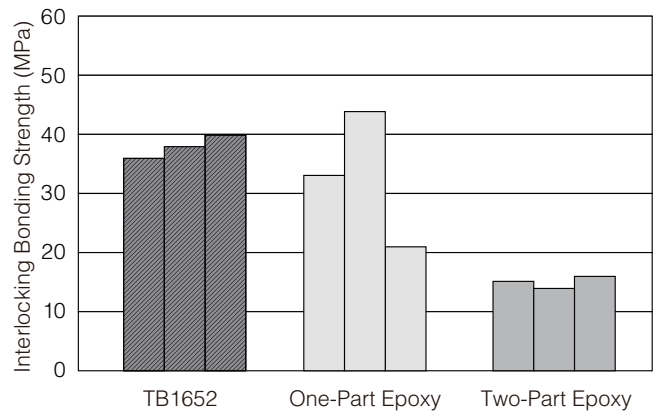
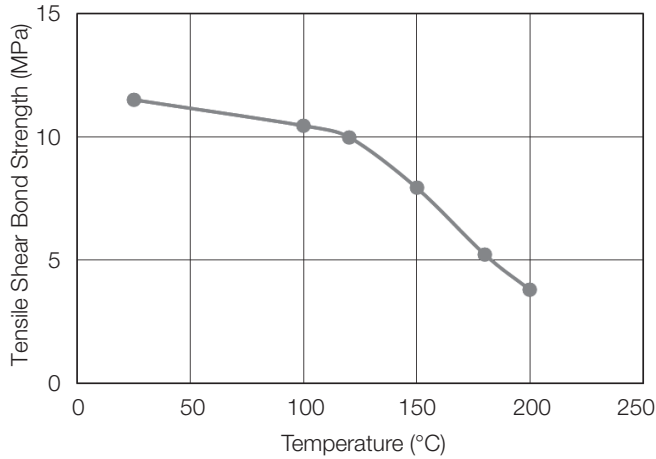


Fig. 13 Interlocking Bonding Strength Comparison

- \*Measurement method: 3TS-305-01
- \*Test piece: Stainless steel 304 pin, collar (adhesive area φ6×15mm, clearance 1/10mm, sheet film thickness 40µm)

## 4-2 Measurement of Tensile Shear Bond Strength During Curing

The expanding adhesive sheet has excellent heat resistance. Even in high temperature environments such as 150°C, it still maintains approximately 70% adhesive strength at room temperature (Fig. 14)

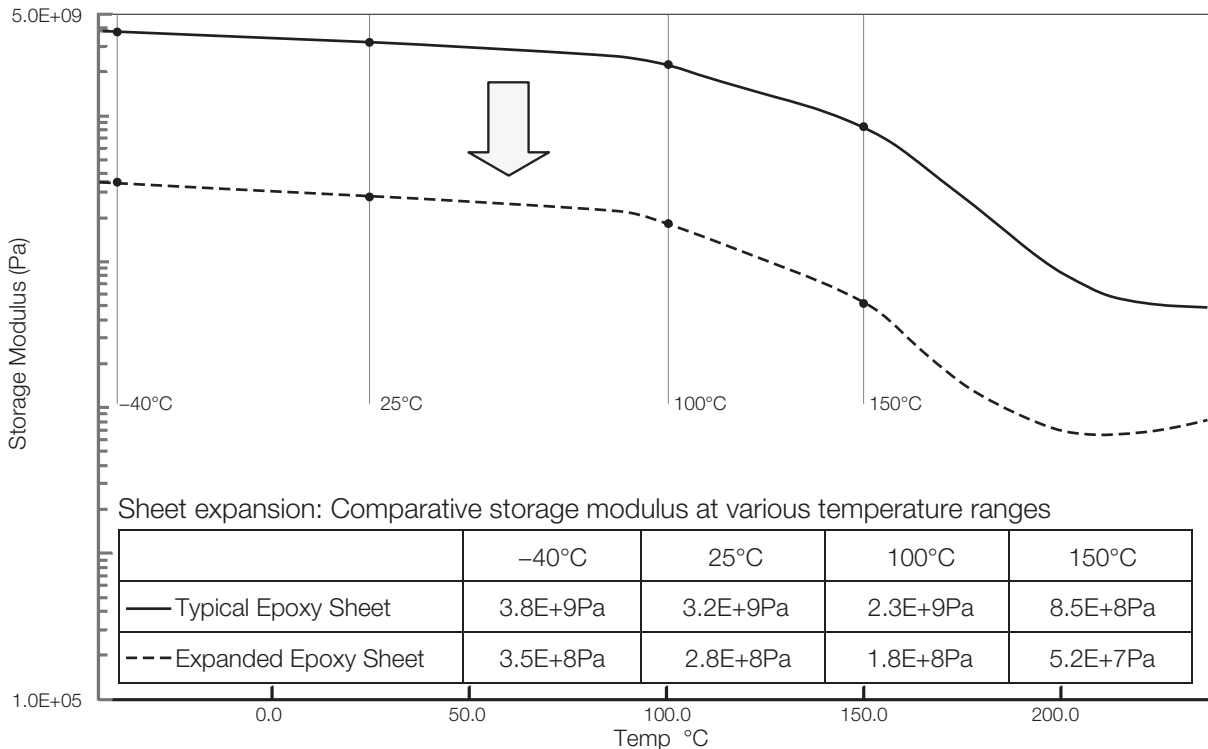


**Fig. 14 Changes in Tensile Shear Bond Strength at Various Ambient Temperatures**

- \*Measurement method: 3TS-301-21
- \*Curing conditions: 150°C×30min.
- \*Test piece: Fe/Fe t2.0×25×100mm, clearance 50μm, sheet film thickness 40μm

## 4-3 Adhesion to Plastic

Though the expanding adhesive sheet has high heat resistance and a high T<sub>g</sub> (glass transition temperature), modulus of elasticity is low compared to typical epoxy



**Fig. 15 DMA Storage Modulus Measurement**

\*DMA E', frequency: 1Hz

sheets. It is considered that this reduction in the modulus of elasticity is the result of sheet volume expansion.

As a result it has improved adhesiveness in PPS, PPT and other engineering plastics used for automobile parts, which we expect will be utilized in future application (Fig. 15, Table 3).

**Table 3 Improvement in Plastic Adhesion due to Sheet Expansion**

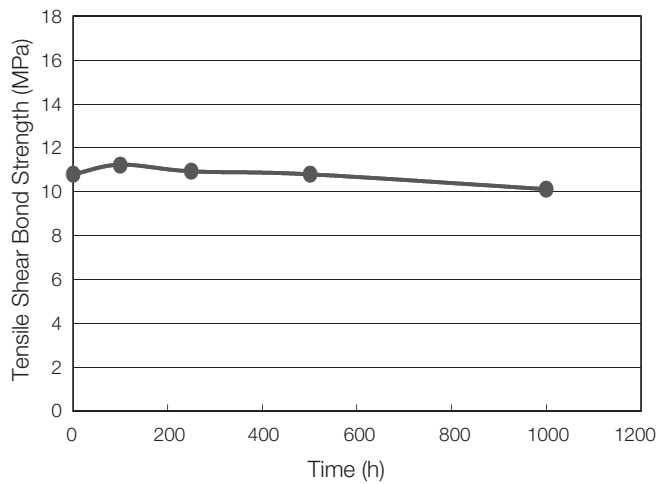
|         | Unit | Typical Epoxy Sheet | Expanded Epoxy Sheet |
|---------|------|---------------------|----------------------|
| PPS/PPS | MPa  | 0.8                 | 2.4                  |
| PBT/PBT | MPa  | 1.1                 | 3.0                  |

- \*Measurement method: 3TS-301-21
- \*Curing conditions: 150°C×30min.
- \*Test piece: Typical epoxy sheet t2.0×25×100mm, no clearance, sheet film thickness 40μm  
Expanded epoxy sheet t2.0×25×100mm, clearance 50μm, sheet film thickness 40μm

## 5. Durability

### 5-1 Automatic Transmission Oil Resistance

We measured the tensile shear bond strength of the expanding adhesive sheet after immersion at 150°C in automatic transmission oil. The expanding adhesive sheet is highly resistant to automatic transmission oil, so swelling and other considerable deterioration is not evident. There was no reduction in tensile shear bond strength when immersed for 1,000 hours (Fig. 16).

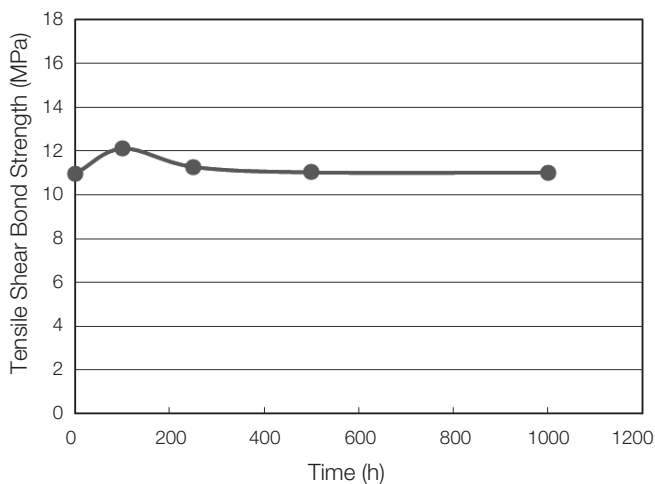


**Fig. 16 Changes in Expanding Adhesive Sheet Tensile Shear Bonding Strength After Immersion in 150°C Automatic Transmission Oil**

\*Measurement method: 3TS-301-21  
 \*Curing conditions: 150°C×30min.  
 \*Test piece: Fe/Fe t2.0×25×100mm, clearance 50μm, sheet film thickness 40μm

### 5-2 Adhesive Strength in Heat

We measured changes in the tensile shear bonding strength in a 150°C environment. There was no reduction in tensile shear bond strength after 1,000 hours (Fig. 17).

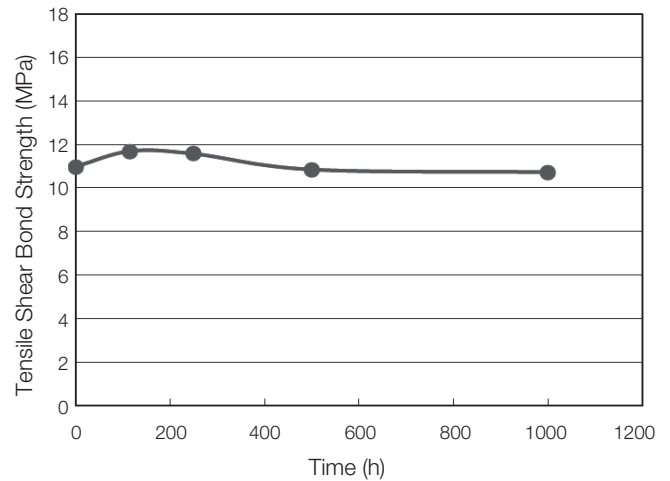


**Fig. 17 Changes in Tensile Shear Bond Strength over Time at 150°C**

\*Measurement method: 3TS-301-21  
 \*Curing conditions: 150°C×30min.  
 \*Test piece: Fe/Fe 2.0×25×100mm, clearance 50μm, sheet film thickness 40μm

### 5-3 Adhesive Strength in Cold

We measured changes in the tensile shear bonding strength in a -40°C environment. There was no reduction in tensile shear bonding strength after 1,000 hours (Fig. 18).



**Fig. 18 Changes in Tensile Shear Bonding Strength over Time at -40°C**

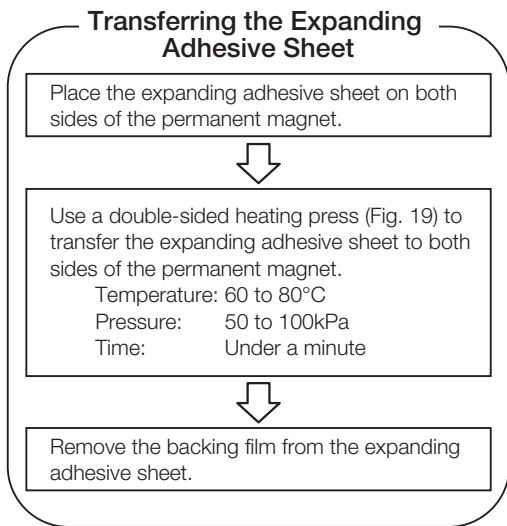
\*Measurement method: 3TS-301-21  
 \*Curing conditions: 150°C×30min.  
 \*Test piece: Fe/Fe 2.0×25×100mm, clearance 50μm, sheet film thickness 40μm

## 6. Transferring the Sheet

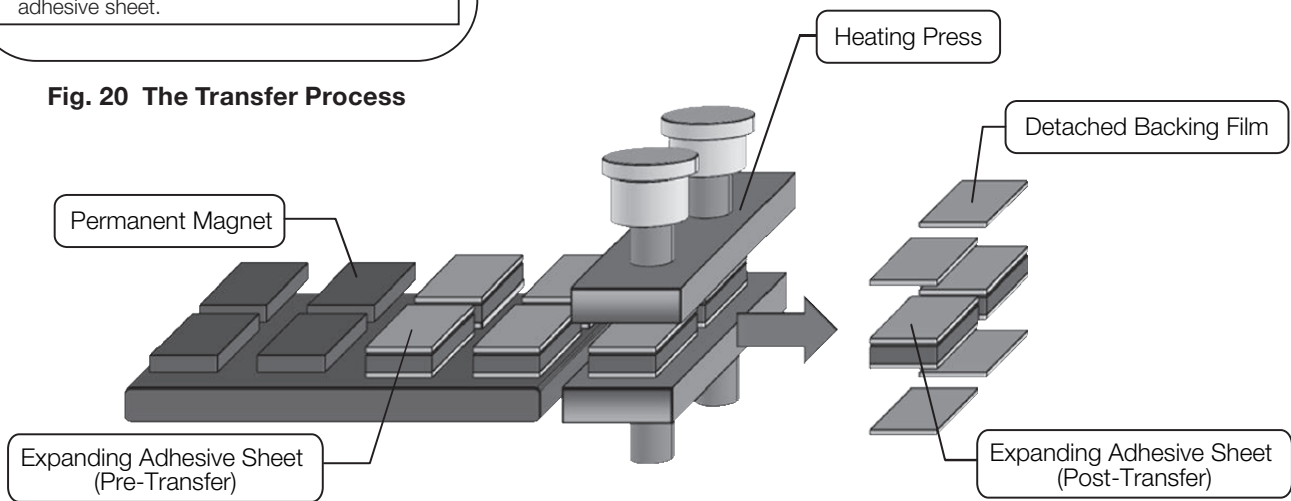
This section details the process for transferring the expanding adhesive sheet to the permanent magnet. Use a double-sided heating press (Fig. 19) to transfer the expanding adhesive sheet to both sides of the permanent magnet. Next, remove the backing film and transfer the expanding adhesive sheet to the surface of the permanent magnet to complete the process (Fig. 20, 21).



**Fig. 19 Double-Sided Heating Press**



**Fig. 20 The Transfer Process**



**Fig. 21 Transferring the Expanding Adhesive Sheet**

## Closing

As the use of electronics in the automobile industry continue to increase, we expect there will be more and more opportunities to explore functional parts utilizing new materials that had never before been adopted for automobiles. This, of course, will lead to the necessity of developing new adhesives and sealants for these new materials and applications. So we at ThreeBond are developing functional sheet materials for our customers' changing needs. As the first step in this endeavor, we are pleased to introduce our heat-curable expanding adhesive sheet, an adhesive for motor-driven automobile motors. Moving forward, we will continue to introduce new materials for a constantly evolving automobile industry that incorporate ThreeBond's proprietary technologies and unique ideas.

**ThreeBond Co., Ltd. R&D Headquarters**  
**Development Division, Functional Materials Department**  
**Yoshihide Arai**  
**Hiroshi Kimura**

**ThreeBond**  
**TECHNICAL NEWS**

**ThreeBond Co., Ltd.**  
 4-3-3 Minamiosawa, Hachioji,  
 Tokyo 192-0398  
 Tel: +81-42-670-5333