

Development of Precoat Adhesive for All Olefin Instrument Panel

Tetsuya ODA*

Atsushi KAWATA*

ABSTRACT

To simplify the production process for vacuum-formed instrument panels, adhesive spray coating of the surface of the plastic foundation has been replaced by pre-coating the bottom side surface of the laminated skin, reducing the number of procedures required for spraying and drying. Further, the development of an adhesive with excellent olefin adhesion qualities has reduced the number of pretreatment steps necessary for the foundation and skin. Adoption of this method has simplified the production process, and reduced the required number of procedures from nine to five, thereby resulting in cost reductions.

1. Introduction

The vacuum forming process is widely used to bond polyvinyl chloride (PVC) laminated with soft polypropylene foam (PPF) skins to automotive interior fitting such as instrument panels (I/P). Adhesives are normally used in this process to bond these soft skins to a foundation. Various changes have been made to make the manufacturing process of interior fittings environmentally friendlier: Solvent-free adhesives have been developed⁽¹⁾, the I/P can be constructed of all olefin materials⁽²⁾, the olefin skins can be recycled to the foundation⁽³⁾, etc.

The change to all olefin I/P has been achieved by changing skin material from PVC to environmentally friendlier chlorine-free thermoplastic olefin (TPO) resin and foundation material from ABS resin to polypropylene (PP). However, the change to olefin has made numerous additional procedures necessary in the manufacturing process. Among these are flame or plasma pretreatment to increase the wettability of the PP (a low-wettability material) in order to achieve adhesion to the skin. In addition, it is now necessary to conduct primer treatment to the soft PPF layer to achieve adhesion.

This paper describes a method of bonding materials during the production of all olefin I/P using the vacuum forming and fitting process. In this method, an adhesive specially developed to bond olefin materials is precoated on the bottom surface of the PPF. This has reduced the amount of pretreatment necessary for skin and foundation, and has led to an extensive reduction in the number of procedures required in the vacuum forming process.

2. Development Concept

2.1. Construction of I/P

Conventional all olefin I/P are composed of an injection-molded PP foundation, a TPO skin, and a PPF cushion layer. The TPO and PPF are laminated, and the bottom surface is treated with a primer. To bond the skin materials and the foundation, pretreatment (flame treatment, etc.) is conducted on the surface of the PP foundation, and adhesive is applied for the vacuum forming and fitting process. Figure 1 shows the makeup of these IPs; asterisks represent materials or treatments which relate to adhesion.

* Tochigi R&D Center

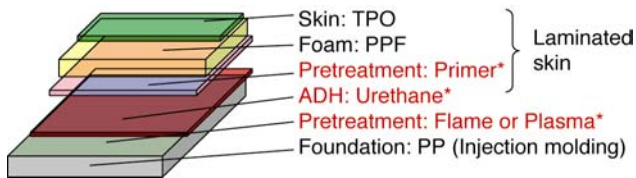


Fig. 1 Construction of instrument panel

(140 °C+) in procedure (6) above, this could be expected to enable more effective adhesion. By giving this precoat adhesive the role of the former pretreatment and adhesive, three adhesive-related processes (2) – (4) would be eliminated. The possibility of eliminating the curing procedure (9) by using a quick-hardening adhesive was also investigated. In addition, it was expected that the use of a precoat adhesive would increase efficiency by enabling continuous application on the skin production line, rather than the conventional spray coating of the foundation in the forming process. (Fig. 3)

2.2. I/P Vacuum Forming Process

Figure 2 shows a representation of the I/P vacuum forming process. The process is made up of nine procedures, as follows:

- (1) Injection molding: The PP is formed into the I/P shape.
- (2) Pretreatment: Plasma or flame treatment is conducted to promote adhesion to the surface of the PP foundation.
- (3) Adhesive coating: Adhesive is sprayed on the surface of the pretreated PP foundation to enable adhesion to the bi-laminate.
- (4) Adhesive drying: The solvents (water) in the adhesive are flashed off.
- (5) Preheating (Heat activation): The adhesive on the surface of the foundation is reactivated by heating in a convection oven.
- (6) Skin heating: The TPO/PPF skin is heated to allow thermoforming into the I/P shape.
- (7) Vacuum forming: The heated TPO/PPF is simultaneously molded and bonded.
- (8) Trimming: Excess skin is removed after bonding from the foundation.
- (9) Curing: The crosslink adhesive is strengthened.

Six of these procedures (2), (3), (4), (5), (7) and (9) are related to adhesion. To further simplify the adhesive-related procedures, this project examined adhesive precoatting of the bottom surface of the skin as a method to reduce the required pretreatment of the foundation and skin, thus allowing a reduction in the number of adhesive-related procedures. In this method, precoat adhesive would replace the primer currently applied to the bottom surface of the skin. Because the adhesive would be activated at a high temperature

3. Difficulties and Solutions

3.1. Difficulties of Precoating

The following technical challenges were addressed through the development of a precoat adhesive for an I/P vacuum forming process.

- (1) Achieving adhesion to PP, a low-wettability and low-adhesion material.
- (2) Initial adhesion properties to allow the adhesive to conform to the complex geometry of the I/P.
- (3) Cohesion capable of resisting temperatures of 100 °C or more when the I/P is exposed to direct sunlight.
- (4) Durability requirements of an automobile interior.
- (5) Measures to prevent adhesion to the mold caused by pre-coating the tooling.

A thermal crosslink system, in which a crosslink reaction is commenced by heating, was adopted in addition to the

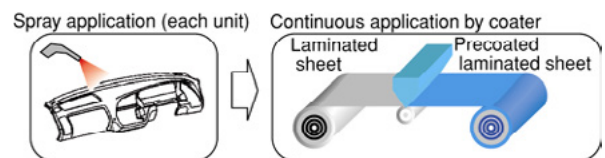


Fig. 3 Change of application system

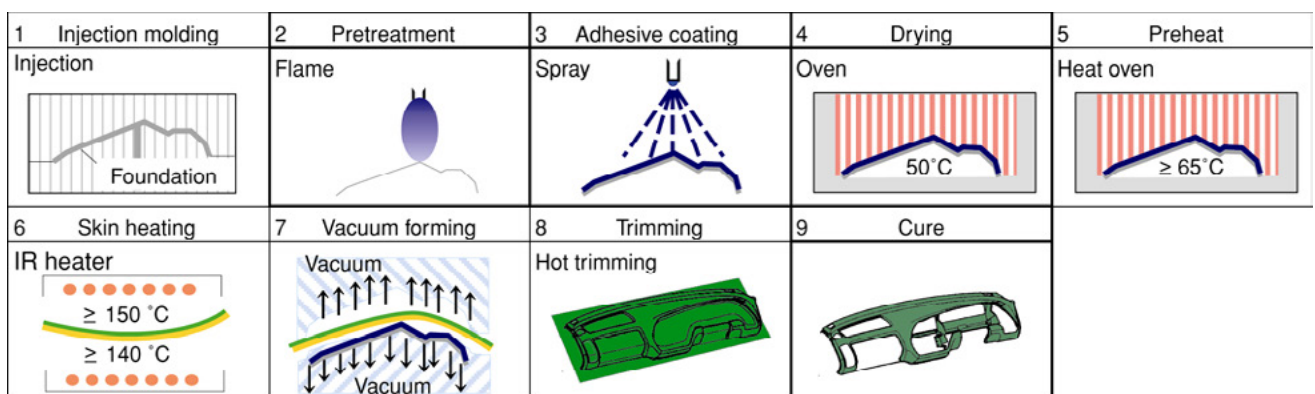


Fig. 2 Vacuum forming process for instrument panel

olefin adhesive which has a high-adhesion property with PP adherent. This made it possible to achieve the required level of heat resistance, durability and reliability. Further reductions in the number of processes involved in the vacuum forming operation were achieved through optimization studies of the adhesive composition and hardening conditions.

3.2. Solutions to Technical Challenges

3.2.1. Adhesion properties to olefin materials (1)

The elements contributing to adhesion to PP were examined at an early stage to enable adhesive precoating.

The following are the most important elements in adhering to PP:

- Wettability of the PP adherent (Adaptability)
- Improving the adhesive's ability to follow minute irregularities on the PP surface (Anchoring effect)

First, to achieve adhesion to the olefin resin, it was important to make the PP (a substance with low adhesion properties) more receptive.

The low surface polarity of olefin (low surface tension: low wettability) surface is a cause of difficulty in adhesion to olefin resin. Adhesion has conventionally been increased through polarization of the olefin surface by coating with a primer, etc., until the surface polarity approached that of the adhesive (rubber, urethane, etc.).

This project examined the feasibility of increasing adhesion performance by developing an adhesive with an olefin structure similar to the base PP.

Solubility parameters (SP value) are an index enabling prediction of the adhesion of two substances.

To ensure adhesion with PP, it is most expedient to select an olefin adhesive with an SP value similar to that of PP. (Table 1). However, olefin adhesives have low SP values and are difficult to dissolve in organic solvents; thereby making the conventional method of spraying, after dispersion in a solvent, unworkable. Olefin adhesives have therefore only been applied in a hot melt type up to the present. Therefore, a functional group was implemented, within the adhesive, with a polarity similar to the base PP to improve adhesion. This functionality enabled dispersion into the solvent while maintaining adhesion to base PP (Fig. 4).

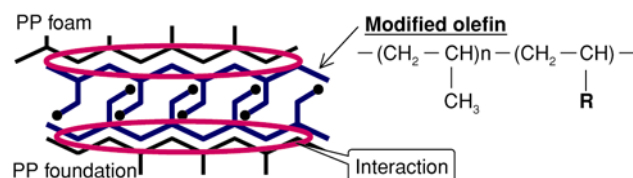


Fig. 4 Adhesion structure model

Adopting a precoating method has made it possible to change the adhesive application method from spraying to the foundation to coating of the skin sheets with a coater. This has increased the degrees of freedom of the application and enabled the use of an olefin adhesive.

3.2.2. Thermal characteristics (2), (3)

Widely varying thermal characteristics are required from the adhesive to enable it to be used in the I/P forming process and resist the temperatures it will be subjected to during use of the vehicle, such as in a closed vehicle cabin in an extremely hot environment. Development proceeded based on hypothetical adhesive temperature characteristics. The adhesive requires flexible characteristics during the pad forming process, in order to improve adhesion (anchoring effect) on minute, uneven, substrate surfaces. On the other hand, for automotive usage it is necessary for the adhesive to have sufficient heat strength (cohesion) to resist high temperatures when the vehicle is left in an extremely hot environment.

Figure 5 shows a thermal history of the skin during the formation process. The laminated skin is raised by heating, and stretched and pressed directly after the temperature required for formation is reached. Figure 6 shows a temperature vs viscosity curve for the adhesive. This data shows that in the 140 °C – 160 °C temperature range, which is required for formation, the adhesive becomes sufficiently soft to follow the uneven contours of the adherend surface.

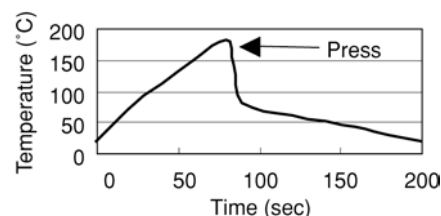


Fig. 5 Temperature of laminated sheet

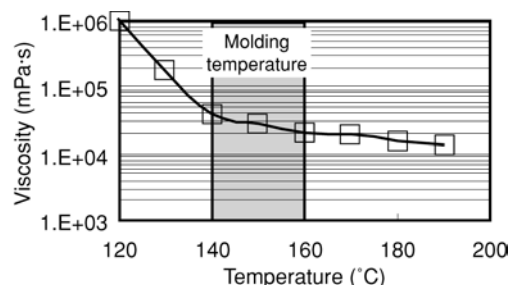


Fig. 6 Temperature vs viscosity curve

Table 1 Adaptability of adhesive

	Substrate (Plastics)	Solubility parameter (SP Value)	Adhesive (Polymers)	Solubility parameter (SP Value)
↑ Low polarity	Teflon	6.2		
	Silicon	7		
	Polypropylene	7.9	Olefin	8
	Polyethylene	7.9		
	Polystyrene	9.2	CR rubber	9.2
	ABS	9.3	EVA	9.4
	Acryl	9.3	Urethane	10
	PVC	9.6	Epoxide	10.4
	PET	10.7	PET	10.5
	Polyamide	13.2	Polyamide	13

In contrast to this, after hardening a high level of cohesion at 110 °C is required of the adhesive in actual use. The modulus is evaluated as an index of cohesion. Figure 7 shows the characteristics of the adhesive from hard to melted

states, and demonstrates that the adhesive is stiff from room temperature up to 110 °C. A reversal of characteristics is required within a temperature difference of only 30 °C (high cohesion at 110 °C, sufficient softness at 140 °C). This is difficult to achieve using the conventional hot melt adhesives, and the thermal crosslinking discussed below was therefore examined.

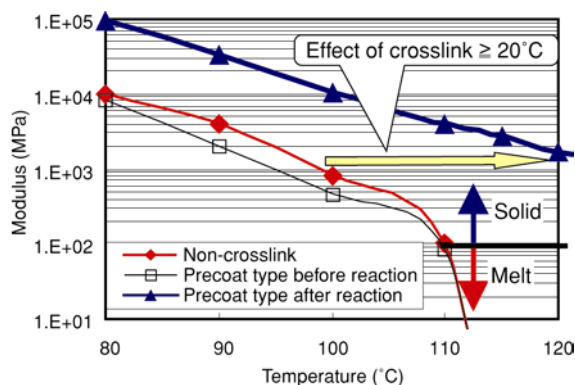


Fig. 7 Temperature vs modulus curve

3.2.3. Mechanism of improved heat resistance (3), (4)

To improve the cohesion of the adhesive when the vehicle is left in an extremely hot environment, a one-component crosslink system was adopted. This system was decided upon, based on the precoating of the bottom surface of the skin and long-term storage post-coating. During storage, it is essential to ensure that adhesion is maintained and that no reaction proceeds. A dormant thermal crosslink system was selected because the reaction will only commence at certain temperatures in this system.

A solvent dispersion system was selected, because heat cannot be applied during the process of production of the skin, due to the characteristics of the thermal crosslink.

Figure 8 shows a model of the mechanism of adhesive curing. At room temperature, solid crosslinking agents are dispersed in the adhesive film. When heat is applied, the base polymer first dissolves, and the crosslinking agents begin to dissolve and disperse. When the reaction commences, a stable three-dimensional structure begins to form. When this structure bonds together, it is impossible to reverse the reaction, and the adhesive will therefore not return to its original state when the temperature drops. In addition, the use of olefin as the base resin has ensured a sufficient level of adhesion with olefin.

The crosslink reaction commences at around the highest temperature reached immediately before the formation

process, but the adhesive is still soft during formation, as shown by the temperature vs modulus curve in Fig. 7. After the crosslink reaction is completed, the modulus shows that heat resistance is improved by more than 20 °C compared to performance before the formation of crosslinks. In addition, the use of a thermal crosslink reaction which cannot be reversed has ensured that a high level of strength is maintained after endurance and deterioration.

3.2.4. Sticking to tooling (5)

Next, methods of preventing the adhesive from sticking to the aluminum mold, a typical concern for precoat adhesives, was studied.

Because the bottom surface of the skin makes direct contact with the tooling at the periphery and openings of the foundation, the precoat adhesive can stick to the tooling and be difficult to remove. The application of a surface release treatment was examined as a method of preventing this phenomenon.

Details of these methods of solving the various difficulties outlined above will be presented in the following section.

4. Basic Adhesive Performance

4.1. Adhesion

Figure 9 shows a magnified photograph of a cross-section of the adhesive layer between the PPF and the PP foundation.

Sufficient wettability is essential in obtaining the required level of adhesion. In this photograph, an extremely thin welding layer can be seen at the boundary of the PP and the adhesive. This is thought to give the adhesive strength. Precoating using an adhesive with a modified olefin base polymer has ensured that the adhesive can be heated sufficiently to achieve dissolution; making the adhesive and the PP highly adaptable and enabling the formation of a welding layer.

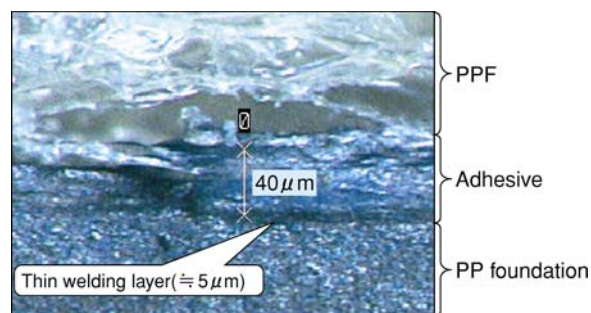


Fig. 9 Section of instrument panel

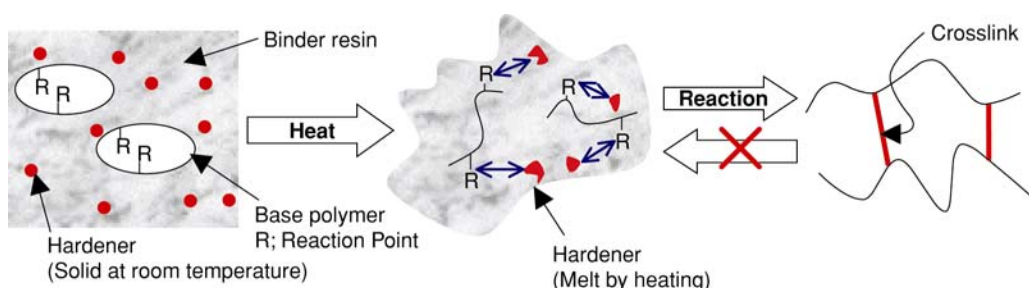


Fig. 8 Increasing toughness

Table 2 Composition of adhesive

Materials			Property	Main purpose
Base resins	Olefin resin	Modified PP A	Low melting point	Adhesion with PP
		Modified PP B	High melting point	↑, Heat resistance
		Modified rubber	—	↑, Flexibility
Additives	Tackifier	Modified rosin	Middle melting point	Initial adhesion
	Hardener	Hardener	Extra high melting point	Reaction with the modified resins
Solvents	Aliphatic	Cyclohexane	bp 81BC	Viscosity control
	Aromatic	Toluene	bp 110BC	Dissolution
	Ketone	MIBK	bp 116BC	Viscosity stability

4.2. Study of Adhesive Composition

The results of the study of adhesive composition conducted in this project are shown in Table 2. The selection of the base polymer is the most important factor in ensuring adhesion. The composition of the adhesive was selected with particular attention to ensuring adhesion with PP. Initial adhesion can be evaluated by measuring initial creep peel length and 180 degree peel strength at 100 °C.

Figure 10 shows the test method. Initial creep is measured by taking a test piece of 25 mm width directly after production and weighting the skin with a 1.96 N load at 90 degree to the foundation. This test piece is left for 30 min. at 80 °C. After this, the length of skin which has peeled from the foundation is measured. 180 degree peel strength is measured by taking a test piece with an identical thermal history to the initial creep test piece and measuring it at the specified temperature in the 180 degree peel strength test specified in JIS K 6829. The heat resistance creep test utilizes the same set-up as for initial creep test, but the test piece is left for 24 hours at 100 °C before peel length is measured.

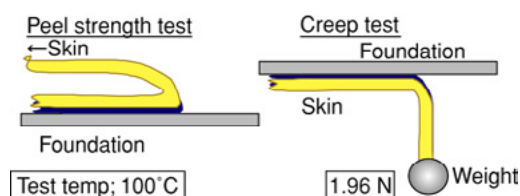


Fig. 10 Adhesion test method

Figure 11 shows results obtained from tests conducted to select a base polymer. The results show an improvement in heat resistance performance obtained by the use of two types of modified PP with different melting points. The resin with a low melting point ensures sufficient softness to allow initial following of the form, while the resin with a high melting point improves heat resistance performance.

Tests also confirmed that using an optimum amount of olefin rubber in the composition of the adhesive has significantly improved peel strength directly after forming. The addition of a rubber component improves ability to follow the form during forming, but an excessive amount of rubber would reduce the modulus in the temperature range in which the I/P will be used. The addition of the correct amount brings the modulus to its maximum value.

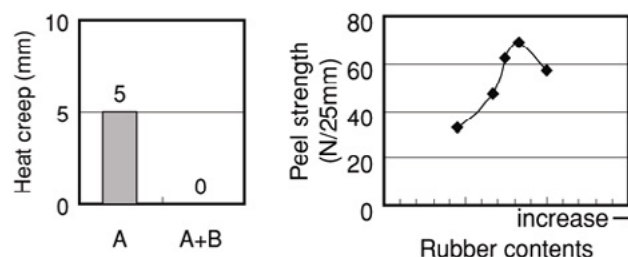


Fig. 11 Base olefin examination

The tackifiers that adjust the adhesive's viscosity were studied next. Making the adhesive viscous increases initial adhesion to the adherent. A functional group was introduced to provide viscosity, leading to a major improvement in peel strength after endurance tests, as shown in Fig. 12.

When introducing a thermal crosslink system, the characteristics of the crosslinking agent must be considered, because they have a significant effect on adhesion. The most important factor in the adoption of thermal crosslinking was the reaction temperature of the crosslinking agent.

Figure 13 shows the relationship between reaction temperature, peel strength and viscosity after storage for 30 days at 40 °C. Because the reaction commences too early when a crosslinking agent with a low reaction temperature is used, the crosslink reaction has already proceeded too far when the materials are bonded, and the adhesive film is too hard to allow sufficient following of the form. This causes adhesion strength to be low. The reaction proceeds slowly if a crosslinking agent which dissolves at room temperature is used, making the adhesive more viscous. These results led to the crosslinking agent with the highest reaction temperature being used.

The results of a study of the mixing ratio of the crosslinking agent are shown in Fig. 14. The relationship between strength and the ratio of crosslinking agent to base resin shown in the figure enabled the selection of a ratio ensuring a sufficient crosslinking effect. This proportion was close to the required proportion theorized from the amount of modification to the resin.

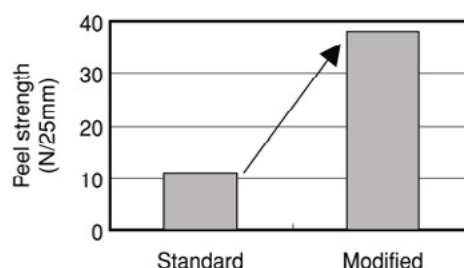


Fig. 12 Effect of modification (after 110°C1000 hr)

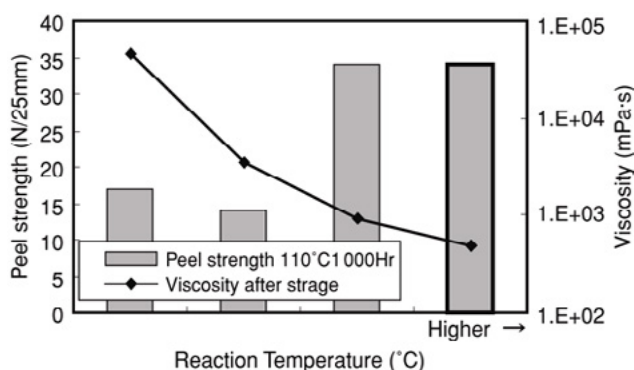


Fig. 13 Reaction temperature of crosslinking agent

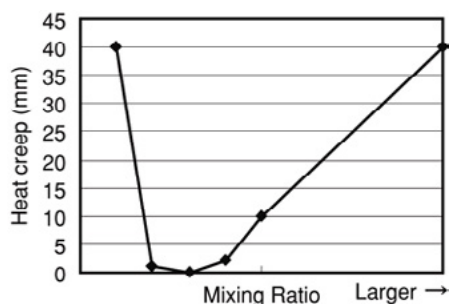


Fig. 14 Mixing ratio of crosslinking agent

The procedures described above made it possible to achieve a basic composition for a pre-coat adhesive with excellent I/P performance. The characteristics of each component were exploited to achieve the performance requirements.

5. Verification of Precoat Characteristics

5.1. Film Thickness Setting

The extensive changes to the forming process entailed by the change to precoat made it necessary to reset various parameters to be controlled at the production site.

The factors, which affect adhesion during the vacuum forming process, are the temperature of the PP foundation, directly before forming, and the adhesive film thickness. The dependence of the adhesion of the new adhesive composition on film thickness and foundation temperature were likewise studied. Figure 15 shows an example of the results of these tests. Creep length was also tested, due to the effect of temperature- and film thickness-dependence. The horizontal axis represents adhesive film thickness, and the vertical axis shows creep length. The smaller the values for creep length, the better the performance.

The example shown is for a foundation temperature of 45 °C, with a minimum film thickness of 17 μm.

Adhesion was studied for various film thicknesses and temperatures. The results of these tests are shown in Fig. 16, and show that the minimum necessary set-up for sufficient adhesion performance are a film thickness of 17 μm and a foundation temperature of 45 °C. This temperature is lower than the minimum temperature of 55 °C for the currently used spray adhesive, leading to benefits for the production process.

Because the skin is stretched to a maximum of twice its size (area ratio) in the vacuum forming process, conditions must be set to ensure that the adhesive film is sufficiently

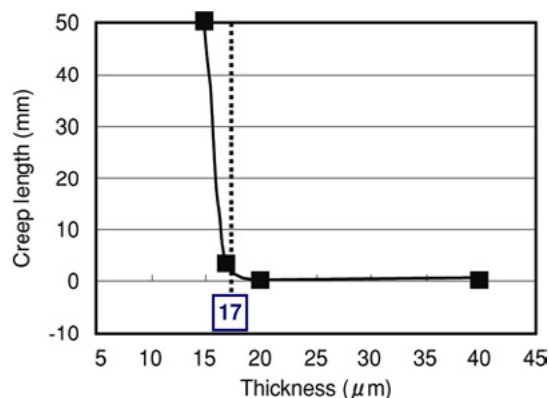


Fig. 15 Initial creep vs adhesive thickness (PP foundation temperature; 45°C)

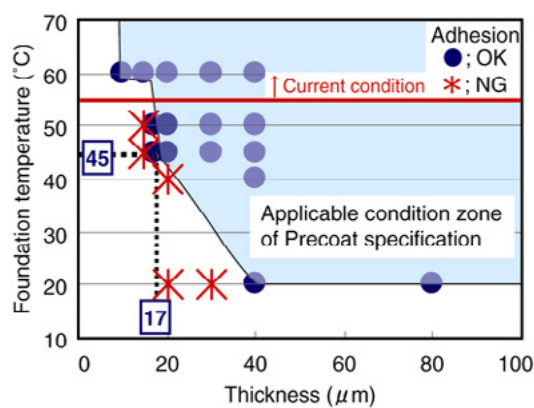


Fig. 16 Foundation temperature vs adhesive thickness

adhesive after stretching. The thickness of the film after stretching is inversely proportional to the degree of stretching the skin, and film thickness therefore halves when the skin is stretched to twice its original area. The minimum film thickness of 17 μm must therefore be doubled to 34 μm for application to the skin during production to maintain adhesion.

5.2. Coating Process

The process of coating the bottom surface of the skin with adhesive was now studied. The skin is coated with precoat adhesive using a conventional coater, and then dried.

It is possible to use various types of conventional liquid coaters, such as roll coaters, knife coaters and gravure coaters.

Figure 17 shows the test results of the accuracy of coating using a roll coater. Film thickness was measured at 516 points for seven production lots. For a target of 40 μm, test results showed a mean value of 40.13, with a standard deviation of 1.49, verifying the performance of this method in actual production. Cp was 1.34 for the lower minimum thickness of 34 μm, demonstrating that the method had achieved the figure of 1.33 required for stability. These results showed that it has been possible to maintain the lower limit of 34 μm, including fluctuation, by establishing a figure of 40 ± 6 μm as the control limit for film thickness on the production line.

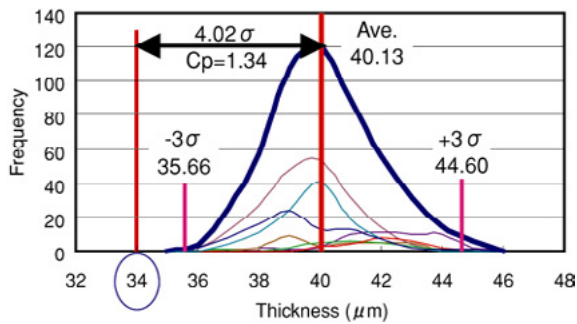


Fig. 17 Range of coating amount

5.3. Durability Performance

Tests were conducted to determine the performance of the adhesive in a finished I/P when applied at minimum film thicknesses. Figure 18 shows the results of tests carried out for the standard film thickness of 40 μm, and a thickness of 30 μm, below the lower limit value. Tests measured the peel strength of I/P formed using specific adhesive film thicknesses after heat aging at 110 °C. The percentages shown in the key represent the degree of stretching the skin was subjected to after formation.

These tests measured heat peel strength under the most severe conditions; results show that high peel strength was maintained even when adhesive thickness was 30 μm, less than the minimum value established by this research, and the sample was aged for 1,500 hrs, 1.5 times the specified time.

It was confirmed that no drop in strength was observed in humidity resistance, thermal cycle resistance, chemical resistance, etc., and all result in PPF break-down.

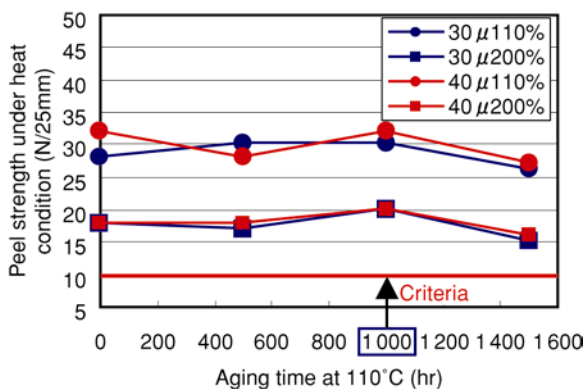


Fig. 18 Heat resistance vs adhesion thickness

5.4. Storage Stability

Two criteria relating to storage were tested to establish the feasibility of the new adhesive for use in I/P production.

One of these was the level of adhesion of the adhesive and the precoated skin after a period of storage. As stated above, precoated skins are often stored for extended periods when the precoat method is used.

To test this, the longest hypothetical period of storage, which would be used during mass production, was established, and test pieces were tested for creep and durability after storage for an extended period.

As Fig. 19 shows, no drop in performance from initial levels was demonstrated in either creep or durability tests, indicating that the new adhesive has good storage characteristics.

In addition to these tests, precoated skins were stacked and stored to test the relation between drying conditions after precoat and the occurrence of blocking, or the adhesion of skins to each other in storage (Figs. 20, 21). When less than 1% of residual solvent remained in the adhesive, blocking did not occur. Drying conditions of more than 80 °C for longer than 60 sec are therefore required to prevent blocking. These results led to 100 °C × 1 min. being established as the drying conditions for the new adhesive.

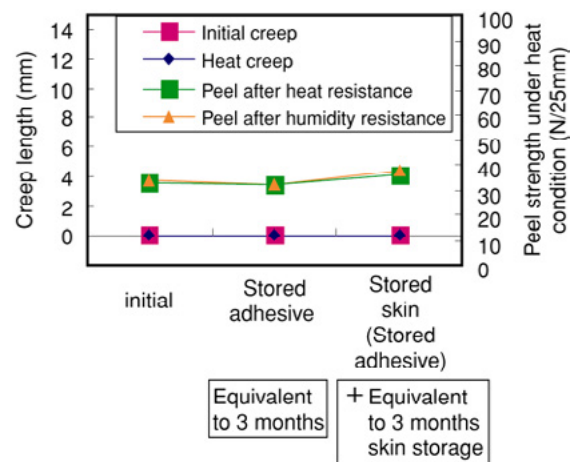


Fig. 19 Adhesion after storage

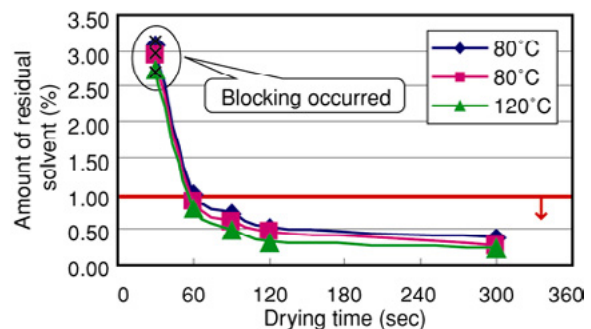


Fig. 20 Drying condition vs residual solvent (blocking)

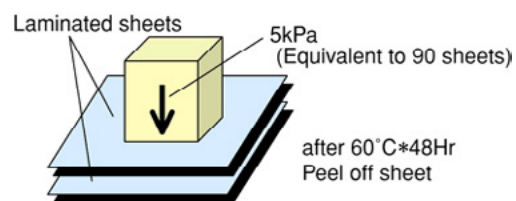


Fig. 21 Sheet blocking test method

5.5. Prevention of Sticking to Tooling

Figure 22 shows the peel strength of the precoat adhesive to aluminum, the material from which the mold is made, at various temperatures. The results demonstrate that peel strength increases with temperature on the untreated aluminum surface. This is because as the temperature of the aluminum adherend increases, the ability of the adhesive to follow the aluminum surface also increases. By contrast, when a silicone surface treatment is applied to the aluminum, desirable peel strength results are obtained not only for 55 °C, the temperature of the mold in the former mass production method, but also for 80 °C. As shown in Table 1, silicone has an SP value lower than that of olefin, ensuring excellent peelability.

A mold releasing composite silicon coating was chosen as the appropriate surface treatment. Silicon resin is the main ingredient of this inorganic coating. The use of a special hardening catalyst has improved dryability at room temperature, and has simplified both the coating operation and maintenance.

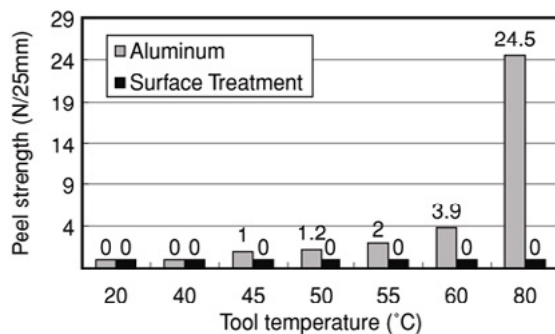


Fig. 22 Sticking to tooling

5.6. Superiority in Actual Production

As previously discussed, the development of a precoat adhesive has enabled a reduction in the number of procedures associated with I/P production, and these reductions have also significantly reduced the number of factors which must be controlled during the formation process. More than ten factors required control in setting conditions for the flame treatment, adhesive coat drying and vacuum forming in the former mass production process. Utilizing a precoat system has reduced these to three: skin storage period, skin heating temperature and PP foundation heating temperature.

Reducing the number of procedures required from nine to five has enabled the space required for production to be reduced from 286 m² to 196 m², or approximately two-thirds of the space presently required. In addition, the cost of production using the vacuum forming method has been reduced by 50%.

6. Conclusion

This research project used the following methods to develop a precoat adhesive for use in the vacuum forming process. This has enabled the number of procedures and the cost associated with the vacuum forming process to be reduced, while maintaining the quality design of vacuum-formed I/P. This will contribute to the broader use of recyclable all olefin I/P.

- (1) A modified olefin resin was used as the base resin to improve adhesion with PP.
- (2) A thermal crosslink reaction system was used to achieve heat resistance at 100 °C and above.
- (3) A composition of adhesive, coating thickness, production conditions, etc., were optimized to achieve high adhesion with PP and maintain a similar level of productivity found in the former method.
- (4) A surface treatment was selected and adopted to prevent sticking to tooling.

The precoat adhesive was developed on the basis of studies of these four factors.

7. Acknowledgments

The authors would like to offer their sincere thanks to everyone, both within Honda and representing other companies, who contributed to the success of this project.

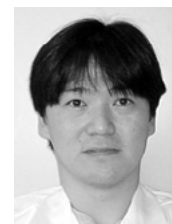
References

- (1) Oyama, M., et al.: Development of a Solvent-free Adhesive for Use in the Vacuum Forming Process, *Journal of Society of Automotive Engineers of Japan*, Vol. 50, No. 5, pp. 40-45 (1996)
- (2) Ito, H., et al.: Development of a 100% Recyclable Instrument Panel, *HONDA R&D Technical Review*, Vol. 10, pp. 158-165 (1998)
- (3) Yamaguchi, T., et al.: A Recycling Technology for Instrument Panel Olefin Skins, *Society of Automotive Engineers of Japan 2001 Spring Lecture Series Advance Collection*, No. 42-01, pp. 13-16 (2001)

■ Authors ■



Tetsuya ODA



Atsushi KAWATA