

Development of an ABS/PA6 Polymer Alloy for Body Panel Applications

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ABSTRACT

An ABS/PA6 polymer alloy has been developed as a resin for body panels of vehicles with an aim toward overall vehicle weight reduction. Compared to conventional resins, this resin has improved surface appearance and the balance between dimensional stability and impact resistance. A “Sink Mark Evaluation Standard” was established for surface appearance, and the ratio of acrylonitrile-butadiene-styrene (ABS) resin and Polyamide6 (PA6) was adjusted to satisfy this standard. An ABS resin ratio of 50% or more was found to be effective for sink mark performance. The filler type and amount were important for the balance between dimensional stability and impact resistance with talc possessing particle diameter of $2\mu\text{m}$ being found to be effective target achievement. This resin shows a 45% weight reduction over steel panel products in the front fender.

1. Introduction

The use of resin body panels has been the subject of investigation for more than 50 years as a means of reducing vehicle weight. Fiber Reinforced Plastic (FRP) and Sheet Molding Compound (SMC) made of thermoset resin reinforced with glass fiber have been used for some time. Recently, advances in materials technology and the desire for recyclability have prompted the use of non-fiber-reinforced thermoplastic resins.

Honda has applied various thermoplastic resins to its mass production models, such as polycarbonate (PC)/acrylonitrile butadiene styrene (ABS) resin polymer alloys⁽¹⁾ for front fenders and other parts, and polyphenylether (PPE)/polyamide 6 (PA6) polymer alloys for such parts as the side sill garnish. It is reported that resin materials that have been developed for body panels by other companies include PPE/polyamide 66 (PA66) polymer alloys, PC/polybutylene terephthalate (PBT) polymer alloys, and other thermoplastic resin materials⁽²⁾.

This paper describes a new thermoplastic resin material which offers superior surface appearance and a balance between the coefficient of linear thermal expansion and impact resistance, and which is capable of reducing the weight of body panels.

2. Development Aims and Concept

2.1. Weight Reduction and Superior Aerodynamic Performance

When fuel efficiency goals are given high priority in car development, it is essential to meet the initial goals for vehicle weight and aerodynamic performance. Aluminum is generally considered the most effective light-weight material because of its relative stiffness.

The graph in Fig.1 shows the weight reducing effects with an equivalent surface stiffness⁽³⁾. This graph indicates that when a steel panel is assigned an arbitrary value of 100,

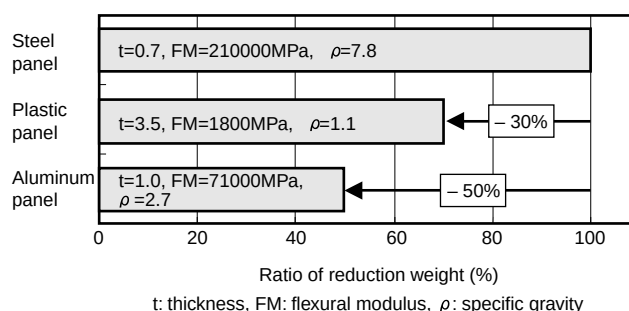


Fig.1 Weight reduction effect at equivalent surface stiffness

resin and aluminum have a weight reducing effects of approximately 30% and 50%, respectively.

However, aluminum has limited formability. Thus, in order to create designs that provide the requisite aerodynamic performance, it is necessary to use an appropriate resins with superior shape flexibility in the appropriate place. Fig.2

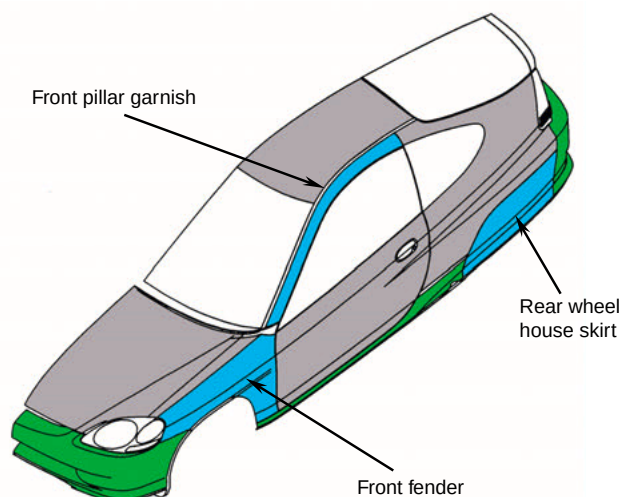


Fig.2 Application of plastic parts for body panel

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provides examples of the shape effects possible with resin components.

2.2. Weight Reduction with Thinner Parts

From the viewpoint of design technology, thinner parts are another possible means of decreasing weight. However, a simply reducing a panel's thickness degrades a part's stiffness, some sort of innovation is needed.

For instance, with resin parts, ribbing is sometimes used on the backside of a part to compensate for the reduction in stiffness due to the reduction in thickness. Such ribbing permits weight reduction by allowing thinner parts that, at the same time, retain the required stiffness.

However, caution is required in creating a design as such ribbing can cause sink marks that degrade the surface appearance of a part.

The authors, by quantifying these sink marks to develop clear standards for product appearance, aimed to develop a resin material that would satisfy surface appearance requirements even when back ribbing is used.

2.3. The Proper Balance Between Dimensional Stability and Impact Resistance

Resin materials exhibit greater dimensional changes under temperature changes than metallic materials and so must have a sufficiently low coefficient of linear thermal expansion in order to minimize the loss of fit and finish quality due to dimensional change. Fillers have generally been considered as a way of reducing the coefficient of linear thermal expansion⁽⁵⁾⁽⁶⁾.

However, because a filler also reduces the impact resistance of resins, the author strove to develop a resin material with both a low coefficient of linear thermal expansion and exceptional impact resistance.

3. Defining Target Value

3.1. Quantification of and Standards for Sink Marks

As there have been no clear criteria for judging sink mark appearance quality, oftentimes judgments are based on visual inspections. This resulted in variations as related to the individual performing the inspection. Therefore, the author decided to define a standard for sink marks that are allowable.

In measuring sink marks in the surfaces of molded parts using a surface roughness tester (Fig.3), depth [V] and width [H] were determined to be the factors necessary to classify sink marks.

Following the classification method in Fig.3, the author created various sink mark samples. It then measured sink

mark depth [V] and width [H] and also had the sink marks visually assessed by a panel of 50 persons to determine the extent of sink mark prominence that is allowable with respect to surface appearance. Based on these results, the range where at least 80% of the panelists judged the sink mark as "allowable with respect to surface appearance" was defined as the "allowable range for sink marks," and the boundary line of that range was defined as the "Sink Mark Evaluation Standard." This allowable range and boundary line are shown in Fig.4. The boundary line is represented as a straight line from the origin to the point with a 7 mm width [H] and 1 mm depth [V].

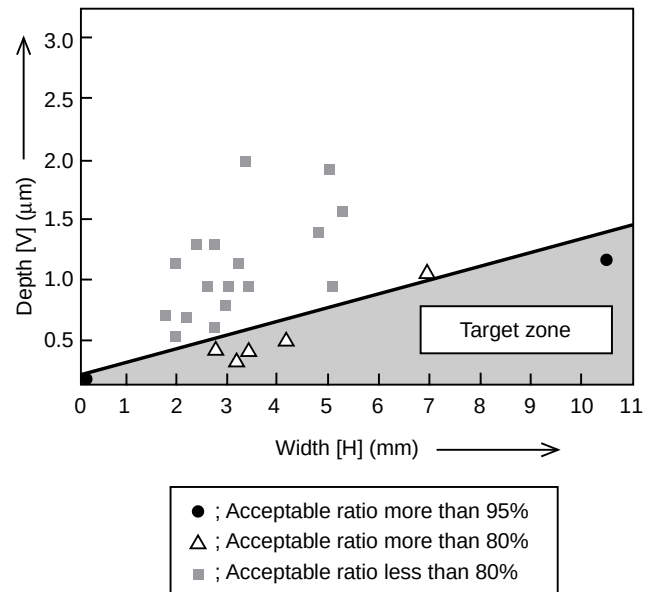


Fig.4 Distribution map of various sink mark profiles

3.2. The Proper Balance Between the Coefficient of Linear Thermal Expansion and Impact Resistance

Table 1 gives, for the parts shown in Fig.2, the maximum length, allowable clearance, the variation in temperature between room temperature and maximum ambient temperature, and the coefficient of linear thermal expansion required in accordance with temperature variation. These data yield a target coefficient of linear thermal expansion for resin materials of $5.5 \times 10^{-5} \text{ cm/cm} \cdot ^\circ\text{C}$ or less.

The target impact resistance was 50J, comparable to that of the ABS/PC polymer alloy, which is being applied to front fenders.

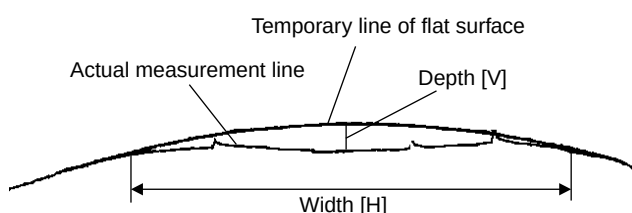


Fig.3 Surface profile of sink mark

Table 1 Limits of CLTE* for applied parts

NO.	Part name	Length (mm)	Allowable dimension change (mm)	Variation in temperature (deg.)	Limits of CLTE ($\times 10^{-5} \text{ cm/cm} \cdot ^\circ\text{C}$)
1	Front fender	850	2.5	50	5.8
2	Front pillar garnish	1 450	4	50	5.5
3	Rear wheel house skirt	700	2	50	5.7

*CLTE: Coefficient Linear Thermal Expansion

4. ABS/PA6 Polymer Alloy

4.1. Reasons for Selecting the ABS/PA6 Polymer Alloy

In the injection molding of a resin, molten resin is injected into a die. It is solidified by cooling as the die with which it is in contact absorbs the resin's heat. It is then removed as a molded part. When the molded part has ribbing, a difference in thermal capacity exists because of the different cross-sectional thickness of the ordinary surface and the rib members. Consequently, the molten resin in each cools and hardens at different rates, resulting in a difference in volumetric shrinkage, which, it is believed, is manifested on the surface as sink marks⁽⁷⁾.

Therefore, resin materials that resist sink mark formation are said to be those that are resistant to the effects of different cooling rates and which have low volumetric shrinkage⁽⁴⁾. As amorphous resin materials have low volumetric shrinkage, the author sought to develop an amorphous ABS resin material offering low cost and broad applicability.

ABS resins have been widely used in interior and exterior automotive parts but normally possess insufficient chemical resistance, impact resistance and dimensional stability for use in body panels. The author therefore considered combining this resin with other resin materials to create improved material performance.

The candidates selected for combination with ABS were PC, PBT, and PA6; the properties of each are shown in Table 2⁽⁸⁾.

The chemical resistance of PC is difficult to improve because of the material's amorphous nature. PBT, a polyester resin with a high specific gravity, is unsuitable for use in

weight reduction applications. PA6 was therefore selected as the component to add to ABS because of its chemical resistance and low specific gravity.

Fig.5 is a transmission electron microscope (TEM) photograph of an ABS/PA6 mixture. The black portions are the ABS resin. As simple mixing results in phase separation (Fig.5-a), a compatibilizer that acts on ABS and PA6 was added to create a polymer alloy with uniform differential scattering (Fig.5-b), thus improving the properties required for use in body panels.

4.2. Effects on Sink Marks

The effects on sink mark formation of this ABS/PA6 polymer alloy were examined using a test die with a general thickness of 2.5 mm and a rib thickness of 1.25 mm. The resin materials examined were ABS/PA6 polymer alloys with an ABS-to-PA6 ratio of 70/30, 50/50, and 40/60. These were compared to polypropylene (PP), which is used in bumpers and instrument panel foundations, and PPE/PA66 polymer alloy, which is used in vehicle body panels. The width [H] and depth [V] of sink marks in samples molded with the test die were measured; the results are in Fig.6.

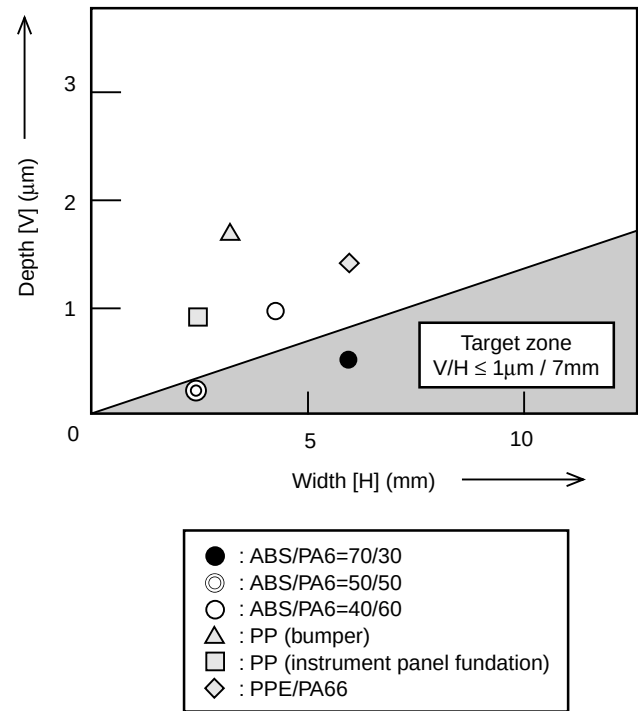


Fig.6 Test results of sink mark measurement

The ABS/PA6 polymer alloys with an ABS resin content of at least 50% were aesthetically effective with respect to sink mark prevention, satisfying the aforementioned sink mark standards. In contrast, PP and the PPE/PA66 polymer alloys fell far short of the standard for sink mark depth.

4.3. The Optimum Balance Between the Coefficient of Linear Thermal Expansion and Impact Resistance

Talc comprising an inorganic mineral filler was added to the ABS/PA6 polymer alloy to determine its effect on the

	PC	PBT	PA6
Chemical resistance	Poor	Good	Good
Specific gravity	1.2	1.4	1.1

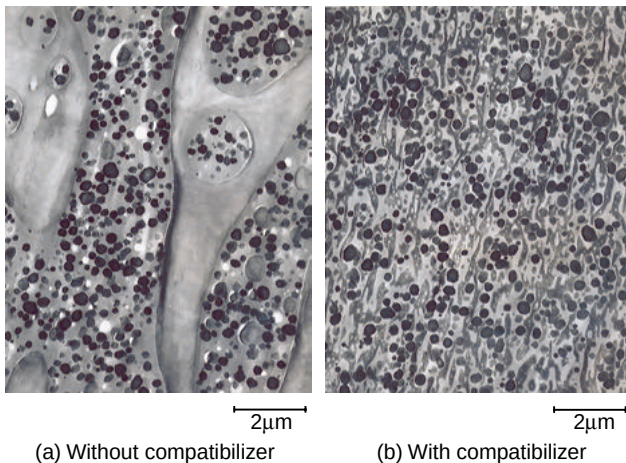


Fig.5 TEM photographs of ABS + PA6 mixture

coefficient of linear thermal expansion. Three types of talc, each with a different particle diameter, were used: 2 mm, 4 mm, and 10 mm. Fig.7 gives the coefficient of linear thermal expansion for different combinations of talc particle diameter and talc quantity.

These results demonstrate how smaller talc particle diameter and greater talc quantity result in a lower coefficient of linear thermal expansion. Talc with a particle diameter of 2 mm was more effective than the other two types in lowering the coefficient of linear thermal expansion, and so was the subject of further investigation.

Fig.8 shows the effect on impact resistance and the coefficient of linear thermal expansion of different quantities of talc having a 2 mm particle diameter. Also shown in Fig.8 for comparison's sake are the properties of an ABS/PC polymer alloy used in actual mass production automobiles.

Impact resistance and the coefficient of linear thermal expansion exhibited a positive correlation. As an impact resistance of 50J or more with a coefficient of linear thermal expansion of $5.5 \times 10^{-5} \text{ cm/cm} \cdot ^\circ\text{C}$ or less was the target for

resin materials for body panels, the composition indicated by an arrow in Fig.8 was selected as the basis for an ABS/PA6 polymer alloy for body panels.

5. Properties of ABS/PA6 Polymer Alloys

Based on the above, the author proceeded with his investigation of ABS/PA6 polymer alloys by focusing on a composition having an ABS content of 50% or more and talc with a particle diameter of 2 mm. Moldability and chemical resistance were optimized by considering ABS and PA6 content and each component's molecular weight, etc., arriving at an ABS/PA6 polymer alloy with the target properties. Table 3 gives the basic properties.

Table 3 Basic properties of the ABS/PA6 polymer alloy

Properties	Typical value
Specific gravity	1.1
Tensile strength	40MPa
Flexural strength	60MPa
Flexural modulus	2200MPa
DuPont impact strength (at -30°C)	53J
Coefficient linear thermal expansion	$5 \times 10^{-5} \text{ cm/cm} \cdot ^\circ\text{C}$

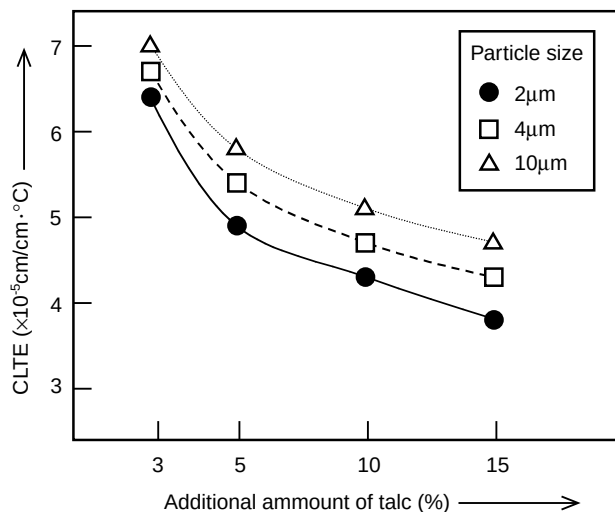


Fig.7 Effect of particle size of talc on CLTE

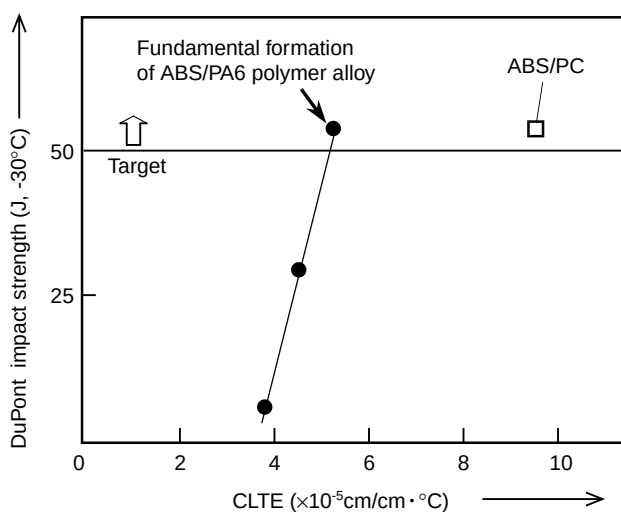


Fig.8 Relationship between DuPont impact strength and CLTE

6. Part Performance

This section discusses the author's investigation of part performance.

6.1. Effects of Rib Sink Marks on Molded Part Surface Appearance

The model in Fig.9-a was used to evaluate the appearance of sink marks caused by ribs in a large molded part (evaluation included deviation). The model used a 1,000 mm x 800 mm model of variable general thickness.

The ribs comprising the rib lattice on the backface of the model had a thickness of 0.8 mm, an intersection of 1.25 mm, and an interval of 100 mm. With general thicknesses of 3.0 mm, 2.5 mm, and 2.2 mm, sink marks were measured at the lattice intersections and in the straight portions between intersections.

Both the depth [V] and width [H] of the sink marks were measured using the method described earlier. The standards for allowable sink marks were as described above: a maximum depth [V] of 1 mm at a width [H] of 7 mm. The measurements for [V] were therefore converted to a 7 mm width equivalent; the mean values and maximum and minimum values of the measurements are shown in Fig.9-b.

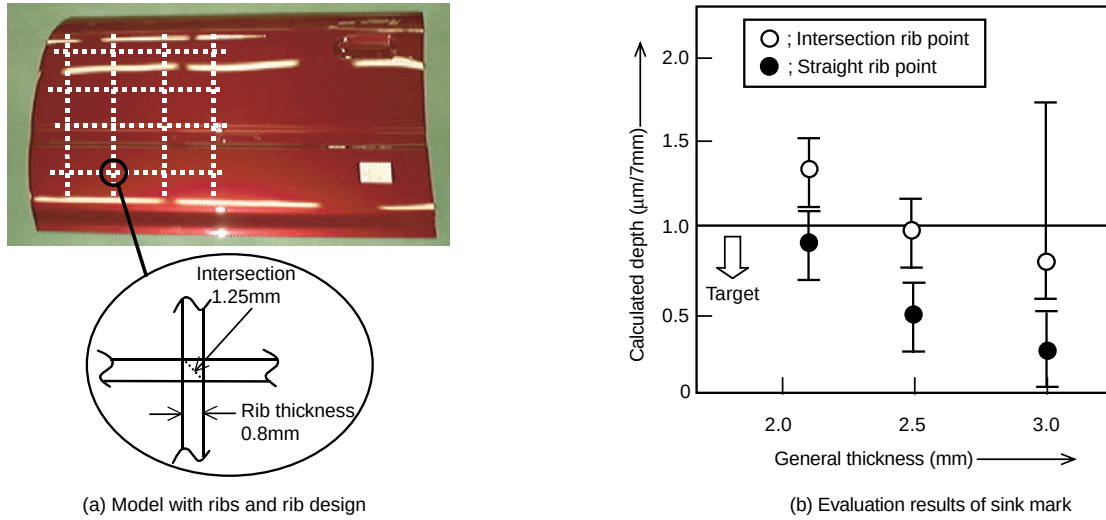


Fig.9 Sink mark appearance evaluation using model with ribs

As the graph in Fig.9-b shows, the aesthetically allowable rib (including variations in the molded parts) when general thickness is 2.5 mm was found to be a straight rib with a thickness of 0.8 mm and no intersections.

6.2. Effect of Ambient Temperature on Product Surface Appearance

A test was carried out to determine the effect of ambient temperature changes on part fit. The results for a front fender, a representative part, are given.

Dimensional change in the front fender was measured after at least four hours of exposure, to an infrared lamp in a 55°C atmosphere thereby raising the fender's surface temperature to 74°C ± 2°C, the high ambient temperature. To develop standards for dimensional changes, measurements were made at seven locations (Fig.10-a) using a hood. Next, dimensional change after at least 4 hours in a -30°C atmosphere, the low ambient temperature, was measured in the same manner as with the high temperature.

The results (Fig.10-b) show that front fender point "a" underwent a maximum dimensional change at the high temperature of 0.5 mm, which was within the allowable

elongation range of 2 mm (the allowable change for point "g" was 0.5 mm).

These results demonstrate the effectiveness of an ABS/PA6 polymer alloy having a low coefficient of linear thermal expansion.

6.3. Impact Resistance at Low Temperatures

The impact resistance of a resin material is normally lower at lower temperatures. Therefore, the author investigated impact resistance in a low-temperature atmosphere (-30°C) likely to be experienced in actual use.

Front fenders mounted to a vehicle were struck with a steel ball attached to a pendulum mechanism in order to evaluate deformation, cracking and other aspects of impact resistance. The impacted part is shown in Fig.11. The steel ball weighed 4 kg and was positioned at a height of 50 cm.

Fig.12 shows the results of this impact resistance test, in which two types of front fender were used: one made of ABS/PA6 polymer alloy, the other made from a steel panel. Test results were assessed on the basis of deformation area.

In contrast to the steel fender, whose extremely large deformation area would have necessitated replacement, the

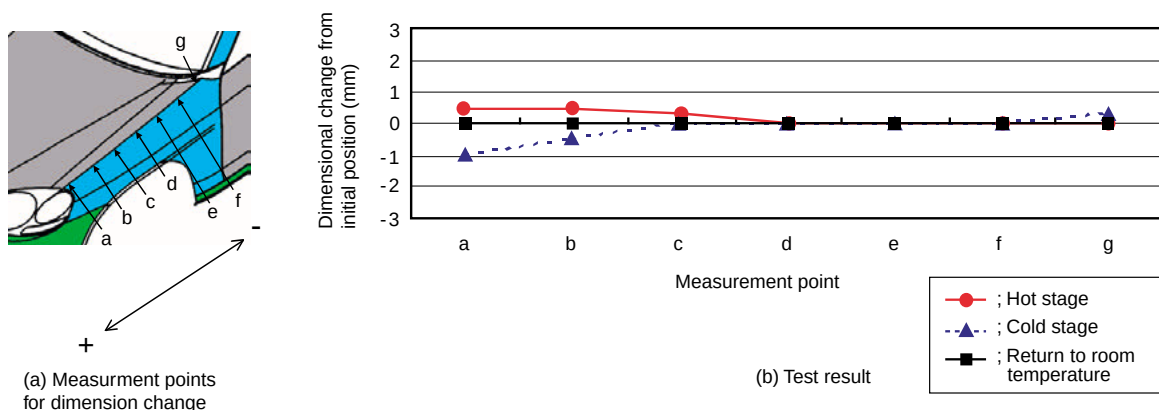


Fig.10 Hot-cold cycle test for front fender

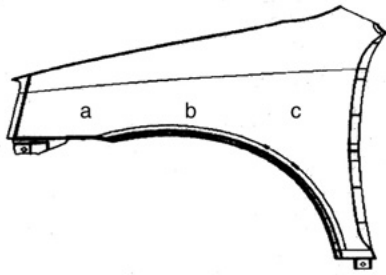


Fig.11 Impact test points on front fender

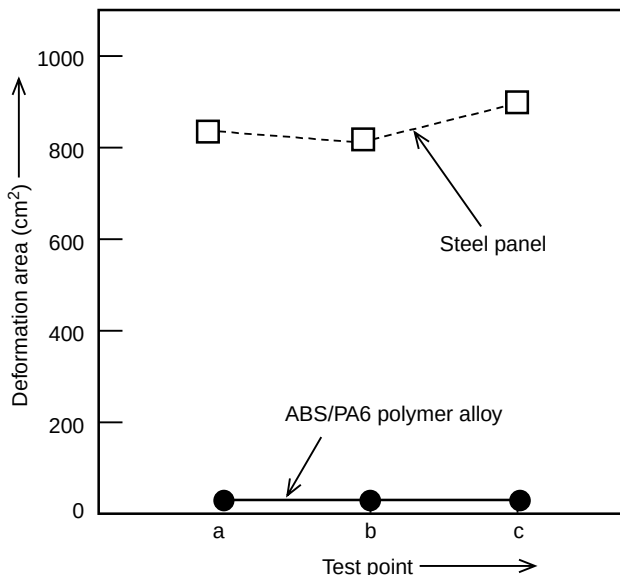


Fig.12 Comparison of deformation area between ABS/PA6 polymer alloy and a steel panel

ABS/PA6 polymer alloy fender showed no cracking and no large deformation, even in a -30°C atmosphere, thus demonstrating its superiority as a flexible resin material.

7. Conclusions

An ABS/PA6 polymer alloy for body panels was developed as a means to decrease automobile weight. The material's properties were enhanced through an investigation of sink marks on a model with ribs and dimensional changes resulting from changes in ambient temperature.

Sink marks were prevented by making use of the properties of amorphous ABS resin; dimensional stability was assured with a filler of optimum type and quantity, and optimum balance between the coefficient of linear thermal expansion and impact resistance.

The author's findings are as follows.

- (1) Maximum allowable sink marks were those with a depth [V] of 1 mm and a width of [H] 7 mm.
- (2) An ABS resin content of at least 50% was effective in preventing sink marks.
- (3) Talc with a particle diameter of 2 mm was effective in lowering the coefficient of linear thermal expansion while

also assuring proper impact resistance.

An ABS/PA6 polymer alloy front fender with a general thickness of 2.5 mm and a weight of 1.17 kg was 45% lighter than a similar steel front fender.

8. Acknowledgments

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