

Development of High-Rigidity Polypropylene Material and Clear Coat for Lightweight Bumper Fascia

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ABSTRACT

A polypropylene material and clear coat were developed for the purpose of reducing bumper fascia weight.

In order to reduce bumper fascia weight, a polypropylene material was developed that would make it possible to thin the average wall thickness of 3.0 mm down to 2.0 mm. The developed material has high flowability to enable injection at 2.0 mm, and steps were taken to augment its rigidity by making it a high-rigidity material. At the same time, attention was also paid to the reduction in impact resistance caused by the higher rigidity, and to the fact that it would be further reduced after coating. That reduction in impact resistance was therefore limited by developing not only a material but also a coating for the purpose. Of the primer, base, and clear layers that make up the bumper fascia coating, the origin of cracking is in the clear layer. The main component of the clear layer is acrylic resin, and the glass transition temperature of this resin was raised while also adding an admixture of resin particles with a diameter of 0.1 μm or less. This was done to make the coating hard and brittle, increasing the number of cracks in order to distribute the stress.

As a result, a weight reduction of 23% or more relative to preceding materials was achieved in the bumper fascia of the 2016 model CIVIC.

1. Introduction

There are high levels of concern about reducing carbon dioxide emissions in order to protect the global environment. In the lifecycle of a motor vehicle, CO₂ emissions during driving make up a high percentage, and reductions in CO₂ emissions are being sought by means of improved fuel economy. Achieving reductions in vehicle body weight is considered important for the purpose of improving fuel economy, and many parts are being examined to this end.

The combined weight of the front and rear bumper fascia for a single vehicle is around 8 kg, making these large trim parts where weight reduction could be expected to have an impact (Fig. 1). Methods used to achieve such a weight reduction include, for example, using material with a lower specific gravity and reducing wall thickness. Since the material being used is polypropylene (PP), which already has a low specific gravity, reports of measures in this area mainly involve technology for reducing wall thickness⁽¹⁾.

Since reducing wall thickness lowers moldability, rigidity, and impact resistance, ways of enhancing performance of thin-wall parts by means of parts design,

material, and manufacturing methods are being investigated. In materials, in particular, investigations are being made of the properties and proportional balance of the three components that make up PP material, namely PP resin, talc filler admixture, and rubber.

Injection molding is used to mold the bumper fascia, but when wall thickness is reduced, the flowability in the mold is reduced, lowering the moldability. In order to heighten moldability, therefore, it is necessary to heighten the PP material flowability.

When the bumper fascia wall thickness is reduced, the rigidity is lowered so that the pushing force on the



Fig. 1 Front and rear bumper fascia

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fascia when applying wax causes elastic buckling in the parts. Therefore high rigidity material is necessary. Furthermore, the properties of PP material change with the temperature, so that the impact resistance of the material in low-temperature environments is lower than at normal temperatures⁽²⁾. There would be concern that the parts could be damaged by external force in the kind of low-temperature environments found in North America and Russia in wintertime, when the impact resistance of the parts would be lowered, and it is therefore necessary to heighten the impact resistance.

On the other hand, as shown in Fig. 2, PP material rigidity and impact resistance are in an inverse relationship. Moreover, impact resistance at low temperatures after coating is lower than before coating. This means that it is no simple matter to achieve a balance between material rigidity and post-coating impact resistance at low temperatures, and so to obtain a large weight reduction effect, by means of PP material development alone. It was reasoned, therefore, that if a coating that would limit the reduction in impact resistance at low temperatures could be developed, then a balance between rigidity and impact resistance could be achieved. This paper introduces the new development of PP material for use in reducing wall thickness as well as of a coating that limits the reduction in impact resistance at low temperatures.

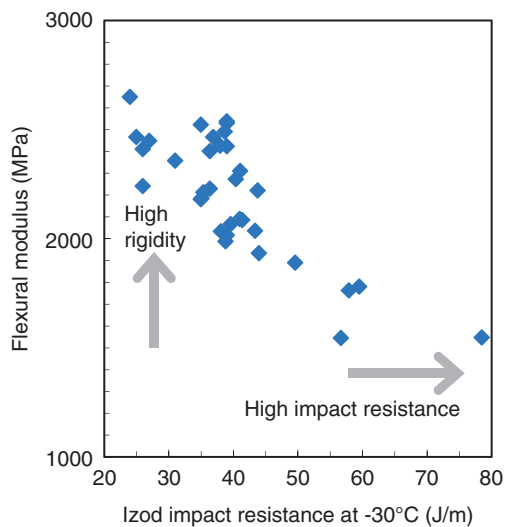


Fig. 2 Relationship between impact resistance and rigidity

2. Conceptual Approach of Coating for Limiting Reduction in Impact Resistance

The coating on ordinary bumper fascia is composed of three layers. These are the primer coat, which assures adhesion of the coating to the PP material, the base coat,

which provides the color, and the clear coat, which protects the coating from ultraviolet radiation (Fig. 3).

The post-coating impact resistance at low temperatures was evaluated using a modified Dupont impact tester according to paragraph 6⁽³⁾ of JIS K5600-5-3 (Fig. 4). A test plate cooled down to -30°C has a weight of 1 kg dropped onto it from a set height, and if the test plate does not break apart, it is considered up to standard. The drop height is

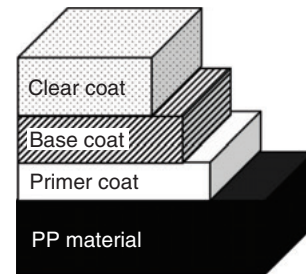


Fig. 3 Construction of bumper fascia coatings

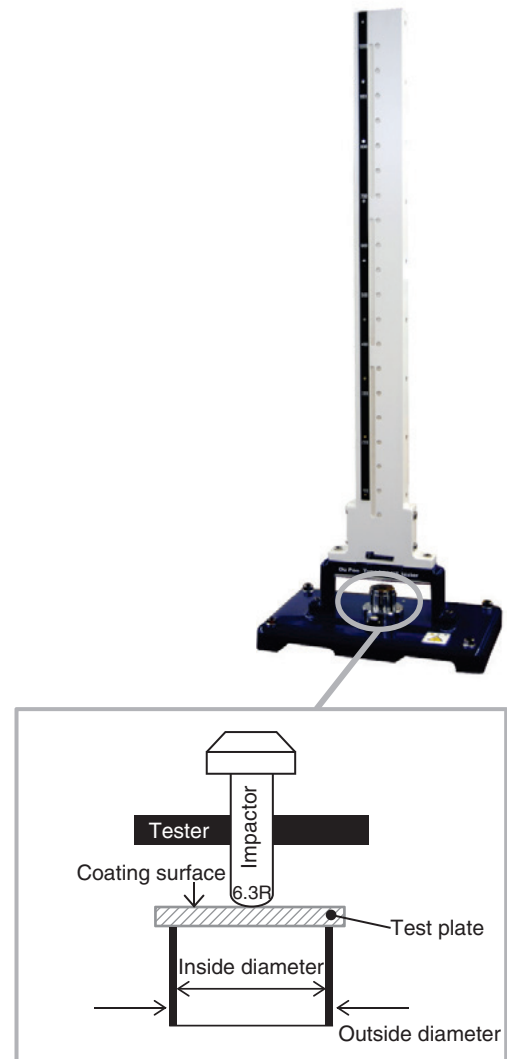


Fig. 4 Modified Dupont impact tester

raised 10 cm at a time, and at the height where the test plate breaks apart, it is considered to fail the test. The maximum height where no breaking apart occurs is taken as the impact value. The ways in which the bumper fascia are used was studied and an impact value target was set at which the parts would not break in the actual use environment.

The fracture surface of test plates that broke apart in the post-coating low-temperature impact test were observed using a scanning electron microscope (SEM), and the results are shown in Fig. 5. It was apparent that the cracking originated in the coating and advanced to the surface of the PP material, then propagated to the bottom surface.

Figure 6 shows the relationship between the three coating layers and impact resistance. The material without any coating, with only the primer coat, and with the primer coat and base coat, exhibit no difference in their impact resistance. When coated with primer, base, and clear coats, however, the impact resistance is lower.

Based on the fracture surface observation results together with the relationship between the various coats and the impact resistance, it was reasoned that breaking apart occurs as follows. An external force causes the test plate to deform. Unable to follow this deformation, the clear coat surface cracks, the cracking propagates to the base, the primer, and the PP material, in that order, resulting in the PP material breaking apart. Since the origin of the cracking is in the clear coat, the possibility of changing the resin properties in the clear coat so as to limit the lowering of the impact resistance was investigated.

Two types of clear coat resin properties were considered for the purpose of limiting the propagation of cracking. The first was a soft type that would conform to the deformation under external force. The second was a hard type that was intended to prevent the development of certain specific types of cracking that advance faster than others by instead making the clear coat more susceptible to cracking and increasing the number of cracks in order to distribute the stress, thereby limiting the development of cracking. The soft type would become sticky when the clear coating surface grew softer in the summer heat, making it difficult

to clean, and there was concern that discoloration would reduce the market appeal of its external appearance. It is no simple matter to configure resin properties so as to achieve a balance between clear coat staining properties under high temperatures and impact resistance under low temperatures.

The hard type makes the clear coat more susceptible to cracking and this causes the coating to lose some of its flexibility. There was concern that cracking of the coating

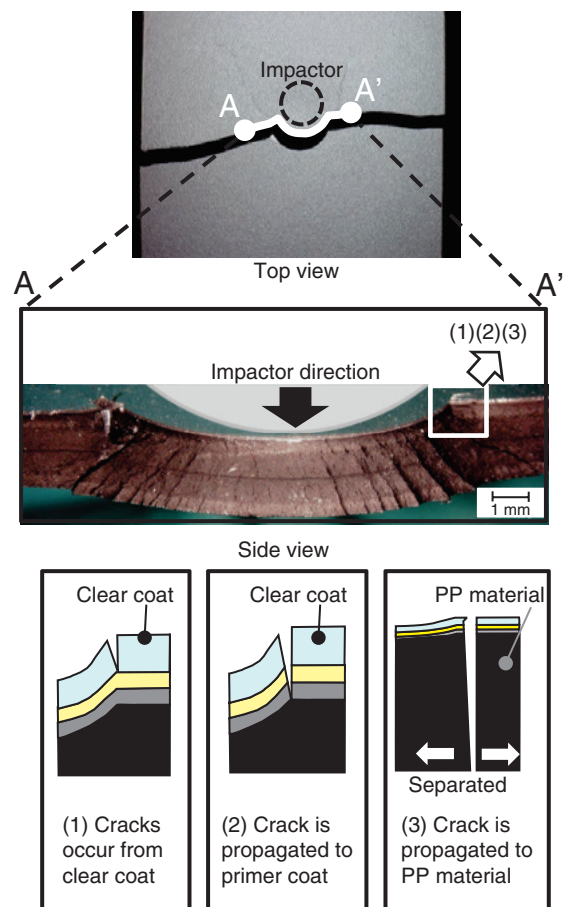


Fig. 5 SEM photograph of broken panel

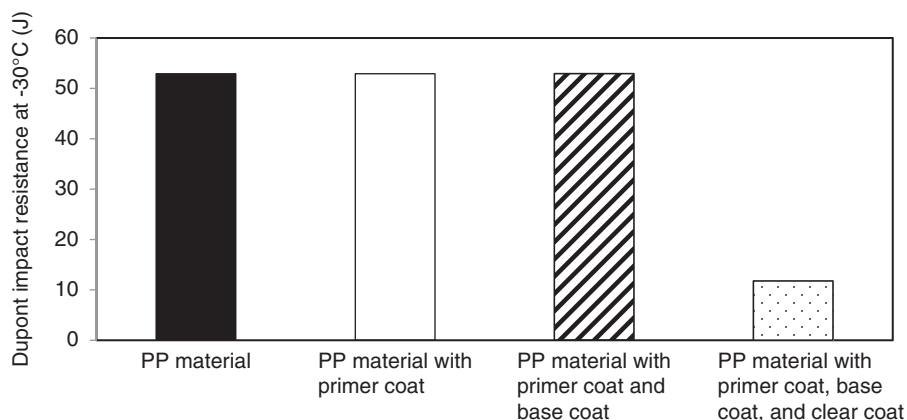


Fig. 6 Impact resistance of 3.0 mm PP material with coatings

could occur when installing or removing the bumper fascia, and that this would reduce the market appeal of its external appearance. It was reasoned, however, that the resin properties could be configured if the fascia could be designed not to cause cracking of the coating in a bending test that simulated the installation and removal work.

In light of the above, a hard type of stress-distributing clear coating was chosen in order to achieve a balance between functionality on a par with conventional fascia and limitation of the lowering of impact resistance.

3. Development Goals

The target for reduction of wall thickness was determined by studying the weight and average wall thickness of bumper fascia on existing mass-production vehicles. The target for weight reduction was set as 20% or more and average wall thickness as 2.0 mm, which would be competitive with other manufacturers.

(1) Flowability

In order to reduce the average material wall thickness from the conventional 3.0 mm to the thinner 2.0 mm, a target of approximately 50% greater flowability was adopted so that the PP material would flow even at a thickness of 2.0 mm. The melt flow rate (MFR) was used as the index of flowability.

(2) Rigidity

In general, rigidity is in direct proportion to the cube of

plate thickness. In order to assure rigidity in material with an average wall thickness of 2.0 mm that is on a par with material with wall thickness of 3.0 mm, and to achieve a 20% reduction in weight, the specific weight of the material was set to 1.04 g/cm³ or less and the flexural modulus was set to 2200 MPa or greater. Measurement of the flexural modulus was carried out in accordance with ASTM D790⁽⁴⁾.

(3) Impact resistance

The impact value of PP material with and without coating was compared. As shown in Fig. 7, the conventional material (a) with coating, the impact value of the PP material is approximately 80% lower than PP material without coating. (b) When the wall thickness is reduced from 3.0 mm to 2.0 mm, the impact resistance of the PP material is reduced. And (c) when the PP material is made a high-rigidity material, the impact resistance is reduced relative to the conventional material. (d) When PP material that is made with a thin wall and high rigidity has a conventional coating applied, its impact value falls short of the target. (e) Estimating the amount by which impact resistance is reduced in PP material that is made with a thin wall and high rigidity, it was decided to set a limit so that the amount of that reduction would not exceed 50%. The purpose of this limit is to assure post-coating impact resistance at low temperatures.

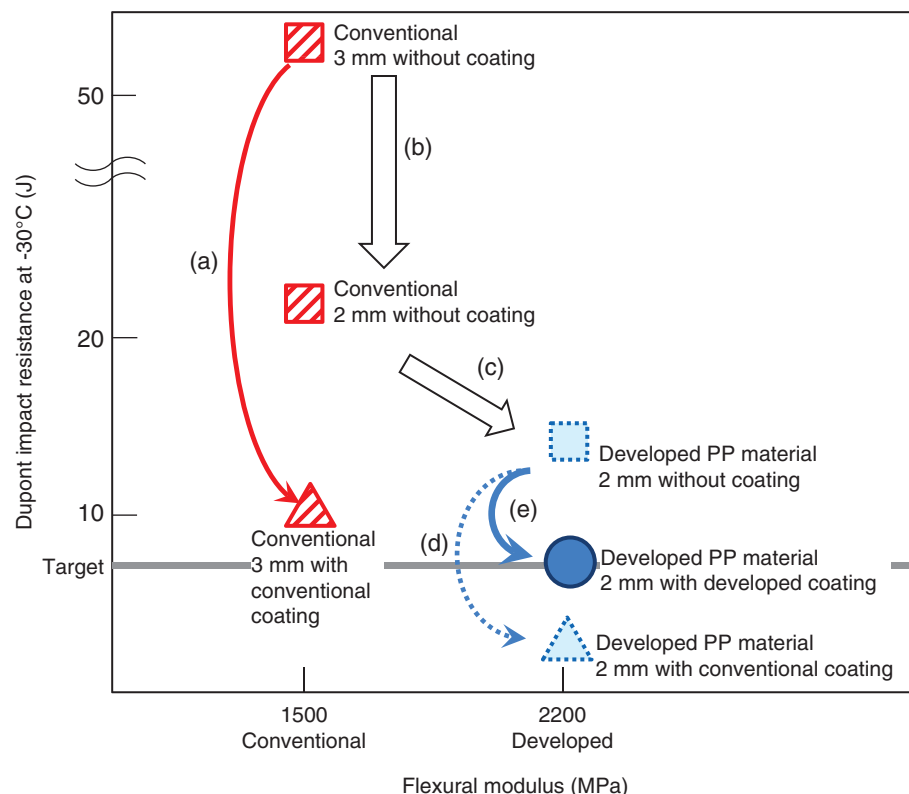


Fig. 7 Relationship between flexural modulus and Dupont impact resistance

Table 1 Properties of conventional and developed PP material

Properties		Conventional	Target value	Developed
Moldability	Melt flow rate (g/10 min)	28	≥ 42	44
Rigidity and weight reduction	Flexural modulus (MPa)	1500	≥ 2200	2280
	Specific gravity (g/cm ³)	0.95	≤ 1.04	1.04

4. Developed Specifications

4.1. PP Material with High Rigidity and High Flowability

The PP material contains a mixture of three components, which are PP resin, talc, and rubber. In order to realize a balance of the target specific gravity and rigidity, the amount of talc, which is a component enhancing rigidity, was increased, while the amount of rubber, which reduces rigidity, was reduced.

Increasing the amount of talc in conventional PP material causes the specific gravity to increase. However, the increase in rigidity achieved by that greater amount of talc is insufficient to achieve the target for rigidity in balance with the increased specific gravity. Therefore the possibility of using a different type of talc in the developed material was investigated. In general, when the admixture contains the same amount of talc, the rigidity-enhancing effect will be greater when the aspect ratio is higher. Therefore a talc with a higher aspect ratio was selected and an amount approximately twice that in conventional material was added to the mixture.

The rubber component on the surface becomes elongated during injection molding and has the effect of enhancing the adhesion of the coating. Therefore there is concern that reducing the amount of rubber would diminish the adhesion. In order to assure the adhesive strength of a stable coating, the amount of the rubber component was reduced approximately 30% relative to the conventional material. Figure 8 shows the ratio of the three raw material components in the PP material.

The heightened flowability was achieved by reducing the average molecular weight of the PP resin, which is the largest component in the PP material admixture, thereby reducing the viscosity of the material. Table 1 shows a comparison of the developed material and conventional material.

4.2. Stress-Distributing Clear Coating Specification

A clear coating of thermosetting urethane is used on the bumper fascia. The acrylic resin that is the main component of this clear coating was designed to be hard and brittle so that the application of external force would cause many cracks in the coating. Specifically, the acrylic resin was made to have a higher glass transition temperature (T_g) than conventional material.

A hard particulate resin was also added to the mixture to function as a starting point for cracking when the coating is deformed. There was concern that using particles of a large diameter in the particulate resin would diffuse light and reduce the luster of the clear coating. Particles with a diameter of 0.1 μm or less, which would be able to maintain the luster, were therefore added to the mixture.

As shown in Fig. 9, raising the acrylic resin T_g and including particulate resin in the admixture enhanced the impact resistance. Use of this clear coating made it possible to limit the reduction in post-coating impact resistance to approximately 50% as compared with approximately 80% with the conventional clear coating (Fig. 10).

The cross-sections of the conventional clear coating and of the stress-distributing clear coating after impact testing were examined by SEM. Figure 11 shows that the cracking of the conventional clear coating due to stress is concentrated at one location. The crack is sharply pointed and is propagated deeply into the base material. The stress-distributing clear coating, however, shows multiple cracks occurring, and the cracking also extends only to shallow depths in the PP material. This indicates that the stress has been distributed and cracking of the material has been limited.

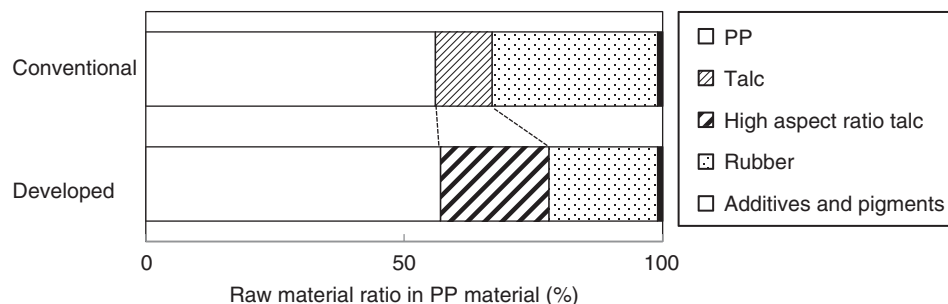


Fig. 8 Comparison of raw material ratio

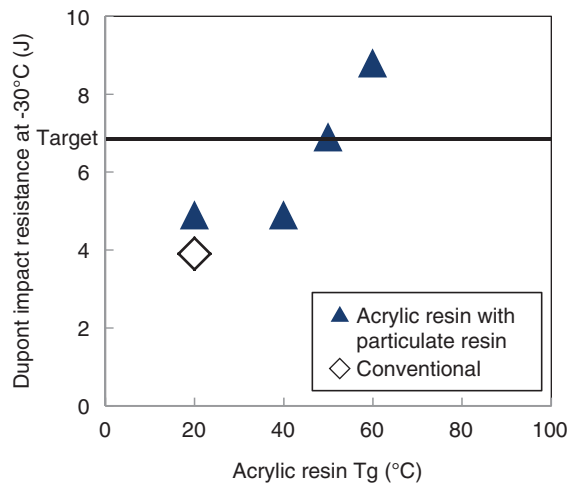


Fig. 9 Relationship between acrylic resin Tg and Dupont impact resistance

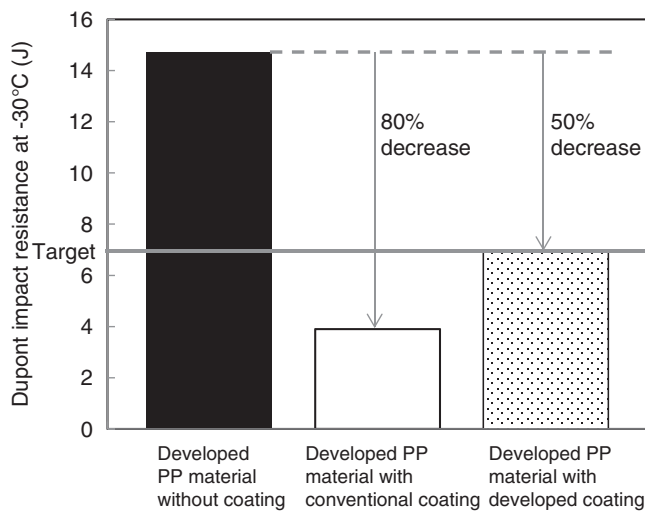


Fig. 10 Dupont impact resistance of developed 2.0 mm PP material with developed coating

5. Product Performance Evaluation

The component performance of bumper fascia with a stress-distributing clear coating on high-rigidity, high-flowability PP material was investigated by means of a pendulum impact test, measurement of the amount of deformation under pushing force, and a component installation and removal test.

Envisioning how a vehicle would be used in a low-temperature environment, the vehicle was fully chilled in a -30°C environment. The bottom portion of the bumper fascia was then subjected to a pendulum impact test, and it was confirmed that damage did not occur.

With regard to elastic buckling of a part caused by pushing force, the amount of deformation that occurred under a fixed load was measured and confirmed to be below the standard value.

With regard to cracking of the coating, verification was conducted by installing and removing the bumper fascia. This confirmed that the market appeal of the part's external appearance was not diminished by cracking.

A thin-wall, lightweight bumper fascia that does not sacrifice the impact resistance and rigidity of the parts was developed. Application of the fascia started with the 2016 model CIVIC. A 23% reduction was achieved in the total weight of the front and rear parts together.

6. Conclusion

The combination of the PP material with the clear coat, both shown below, achieved a balance of rigidity and low-temperature impact resistance while also successfully reducing the bumper fascia wall thickness.

- (1) With respect to the PP material, the viscosity of the PP resin was reduced, thereby enhancing its flowability during injection molding. A talc with a high aspect ratio was also selected, thereby achieving a balance of the target specific gravity and rigidity values.
- (2) With respect to the clear coat, the acrylic resin Tg was

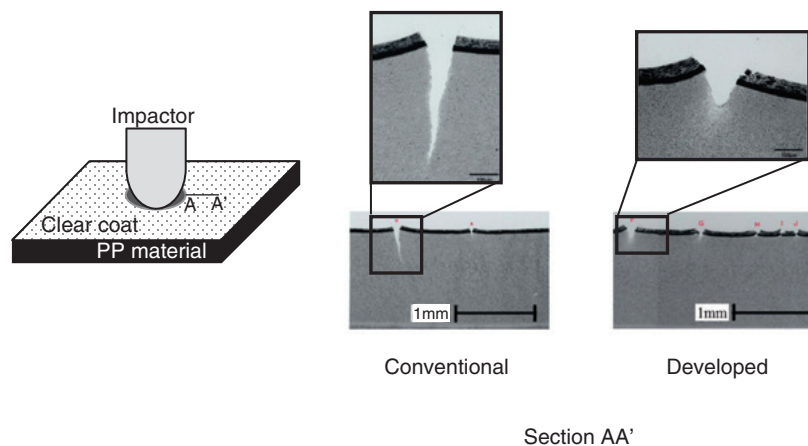


Fig. 11 Section AA' of coated PP after impact test, taken using SEM

raised and particulate resin with a diameter of 0.1 μm or less was mixed in. These measures were used to create a stress-distributing specification with an increased number of starting points for cracking when deformed by external force.

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