

Development of Weight Reduction Technology for Door Trim using Foamed PP

Kenji HIKITA*

ABSTRACT

To reduce vehicle weight, a foaming PP resin was developed as a substrate for the injection molding of door trim. This material was formed by mixing a PP resin that acts as a base with a master batch of foaming agent. The PP resin used as the base is low viscosity to reduce the amount of the injected resin. Non-filled PP resin is also used to lower the specific gravity. Impact-resistance is improved by adding an elastomer. The foaming agent was selected after considering such factors as the uniformity of foam cells, effects on pollution, and the associated work environment. The ratio of foaming agent was selected for a balance between product stiffness and low-temperature impact-resistance. The result is a weight reduction of approximately 25% compared to conventional door-trim substrate material.

1. Introduction

Weight reduction of automobiles is important for improving fuel consumption and addressing environmental issues. Weight reduction of resin components consisting primarily of polypropylene (PP) plays a significant role in this.

The base materials used for automobile interiors is normally PP, and the specific gravity frequently exceeds 1.0 due to the addition of fillers to improve the stiffness, heat resistance and dimensional stability of the base material. Studies have been conducted on reducing vehicle weight by using filled PP to improve the stiffness by increasing the degree of crystallization. Such increased stiffness makes it possible to reduce weight by reducing the thickness of the base material. However, since stiffness is typically proportional to the cube of the sheet thickness, there is the concern of overall stiffness of the base material decreasing as the sheet becomes thinner. When a solution is provided such as incorporating ribs on the back of the product to compensate for this, it becomes difficult to meet the objectives of weight reduction.

By introduction of this new foaming technique, a technology has been developed to obtain greater weight reduction than was possible in the past, while ensuring equivalent levels of stiffness and low-temperature impact resistance (face impact resistance) to those of conventional door trim base materials (filled PP). This paper provides a description of the technology.

2. Development Aim and Concept

2.1. Development Aim

In the case of conventional weight reduction by high crystallization, the amount of filler was increased and the thickness was reduced. As a result, the specific gravity was also increased and the weight reduction effect was 10-15% at the most. The goal of this newly developed foaming technology was to achieve a weight reduction of 20-30%, equivalent to twice the current level of weight reduction, by reducing the thickness due to the effect of high crystallization.

2.2. Weight Reduction Concept

The amount of resin injected must be reduced in order to generate a weight reduction effect. In order to accomplish this, it was decided to pour in resin while using an initial sheet thickness of 2.0 mm instead of the normal 2.5 mm. Although the stiffness of the base material would be decreased as a result of reducing this sheet thickness, it was considered that this loss of stiffness could be compensated for by effectively increasing the sheet thickness through foaming.

Foaming injection molding is performed by opening the mold several millimeters to increase the sheet thickness after the material has been injected. The injection molding process is shown in Fig. 1. Immediately after injecting resin into a mold providing a typical sheet thickness of 2.0 mm, the mold is opened to 4.0 mm to perform foaming to twice the volume

* Tochigi R&D Center

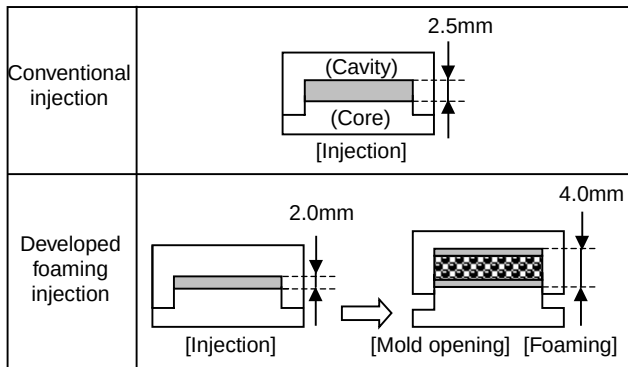


Fig.1 Molding process

of the cavity. Increasing the sheet thickness also increases stiffness. The amount of resin injected could be reduced by 20% as a result of this reduction in the initial sheet thickness.

In order to achieve further weight reduction, a non-filled PP resin was selected. In contrast to the 0.99 specific gravity of the filled PP, the specific gravity of the non-filled PP resin was 0.9. Thus, a weight reduction of approximately 10% could be achieved by applying the material with this lower specific gravity. Thus, theoretically, a total weight reduction of approximately 30% should be possible by applying the measures just described.

2.3. Concept for Improving Stiffness

Fig. 2 shows the relationship between the weight (per square meter) and maximum flex load of non-filled and filled PP resin. The maximum flex load and the slope of the flex modulus incline of three-point bending of a 50-mm test piece were compared to evaluate the product stiffness. The goal was a maximum flex load of 110 N/50 mm for the filled PP having a thickness of 2.5 mm that is used as a conventional door trim base material.

Thickness (mm)	2.0	2.5	3.0
Filled	△	▲	◆
Non-Filled	○	●	

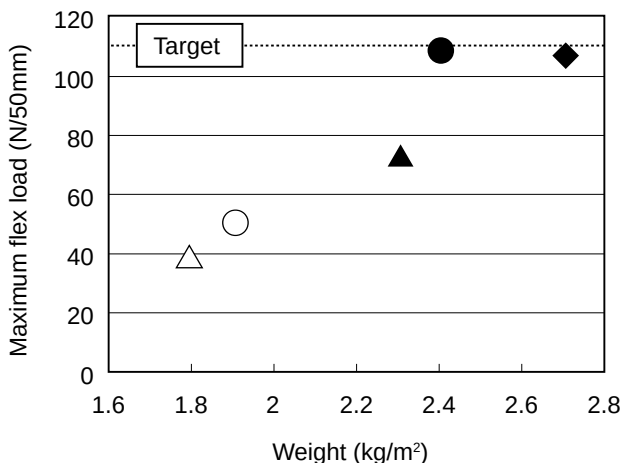


Fig.2 Relationship between weight and maximum flex load

Since the sheet thickness needs to be 3 mm in order to provide a stiffness equal to that of a solid non-filled PP product, the weight ends up increasing. The goal was to obtain a maximum flex load of 110 N/50 mm with an amount of resin equivalent to a sheet thickness of 2.0 mm by using foamed PP resin.

2.4. Concept for Impact Resistance

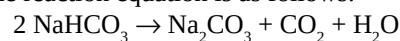
Low-temperature impact resistance (face impact resistance) is one of the requirements of a door trim base material. A base material is considered to be satisfactory if it does not split or crack when subjected to an impact test at -30°C. However, since this test is conducted at the finished product stage, testing was conducted on a conventional door trim base material by using the Dupont impact tester (face impact test) with the finished product as the test piece. The results of the Dupont impact test for filled PP having a thickness of 2.5 mm were 5J at room temperature and 1J at -30°C. These figures were accordingly set as the targets for impact resistance.

3. Material Specifications

3.1. Selection of Material Specifications

3.1.1. Foaming Agent

A foaming agent with a high expansion ratio, uniformly foaming cells and which does not generate noxious gases is ideal. Current foaming agents are classified as either endothermic or exothermic. A typical example of the former agent is sodium bicarbonate which generates sodium carbonate and carbon dioxide gas in an endothermic reaction. The reaction equation is as follows:⁽¹⁾



The expansion ratio of the endothermic type is just under 2 times, and although the foaming strength is slightly inadequate, the foam cells are comparatively uniform.

A typical example of the latter exothermic type is azodicarbon amide (ADCA). Since ammonia gas is produced in an exothermic reaction, there are concerns about such issues as mold corrosion and a poor working environment. In addition, though this type of agent achieves an expansion ratio of 2 times or more, its foam cells tend not to be uniform. The endothermic type was selected as a result of a comprehensive assessment of the available foaming agents.

The PP resin used as the base material and the foaming agent are separately prepared in the form of master batches so that they can be easily handled at the injection molding plant. This is because mixing the two in advance causes a thermal cracking reaction resulting in foaming.

The sheet thickness of the foaming injection molded product was approximately 4 mm, which was obtained by setting the expansion ratio at 2 times, this being the foaming limit of the endothermic type, and the initial sheet thickness was 2 mm to achieve the desired weight reduction. The resulting specific gravity was approximately 0.6.

3.1.2. Specifications of the PP Resin for Injection Molding

The mold clearance is minimized to reduce the amount of resin injected. Thus, if the fluidity of the resin material is

too low, it starts to solidify before it fills the mold resulting in the occurrence of a short shot. It was therefore necessary to increase the fluidity.

Necessary fluidity was determined by using a prototype door mold. Fluidity of resins conventionally used in injection molding exhibit a melt flow rate of approximately 20 g/10 min. These resins easily resulted in a short shot, and thus it was difficult to obtain a satisfactory product. A satisfactory product could be obtained with a resin having a fluidity of 70 g/10 min, so this was used as the basic specification.

There were concerns about insufficient stiffness due to the use of a non-filled PP resin and degraded impact resistance due to foaming. A PP resin was selected which achieved a balance between these two factors. The results are shown in Fig. 3. The relationship between the stiffness and impact resistance was confirmed by varying the amounts of foaming agent (3% and 5%) and the amount of elastomer (0%, 10% and 20%). An amount of foaming agent of 3% or more was needed to satisfy the stiffness criterion of a maximum flex load of 110 N/50 mm. In addition, since the impact resistance was affected by the use of a highly fluid PP resin for the base material, an elastomer was added. The addition of the elastomer at 20% made it possible to meet the target Dupont impact strength of 5J. On the basis of the foregoing results, the specifications of the PP resin for

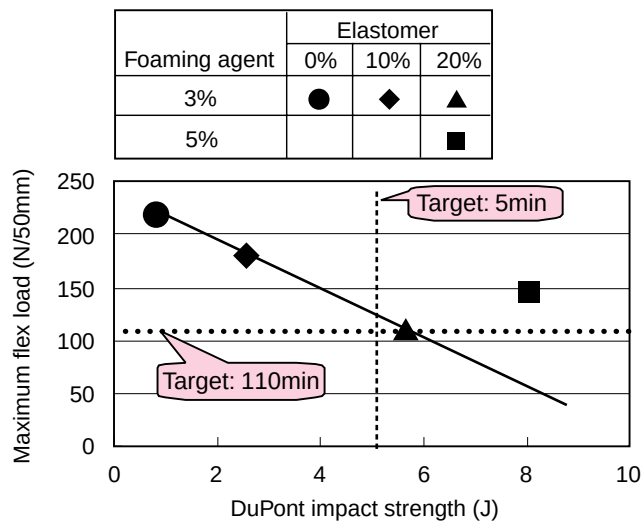


Fig.3 Stiffness and impact absorption of the foamed product

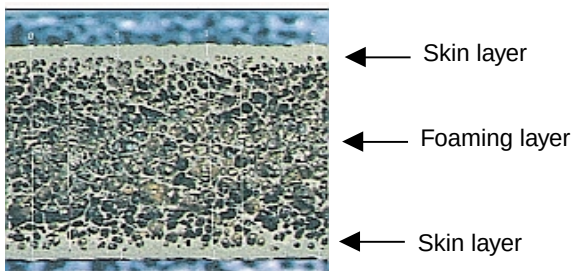


Fig.4 Cross section

Table 1 Typical properties

Properties		Typical value
Melt flow rate 230°C × 21.2N		73g/10min
Specific gravity		0.61
DuPont impact strength	23°C	9J
	- 30°C	1.5J
Tensile yield strength		10.9MPa
Tensile elongation at break		16%
Maximum flex load		113N
Flex modulus incline		92N/cm
Flammability		19mm/min
Fogging value		2.30%

injection molding were set at a foaming agent content of 3% or more and an elastomer content of 20% or more.

A cross-sectional photograph of the foamed product obtained with these material specifications is shown in Fig. 4. Skin layers were formed on both sides of the foaming layer, which was comprised of uniformly foamed cells. The typical properties of this foamed product are shown in Table 1.

3.2. Production Engineering

3.2.1. Molding Conditions

Foaming injection molding is characterized by the foaming step during which the mold is opened immediately after injection. The process is shown in Fig. 5. The process follows the normal injection compression molding procedure through to the final molding step. Following completion of PP resin injection, the mold on the movable side is opened several millimeters. This step is referred to as initial mold opening. In this step, the resin is foamed and then enters a cooling step, after which the mold is fully opened and the product is removed.

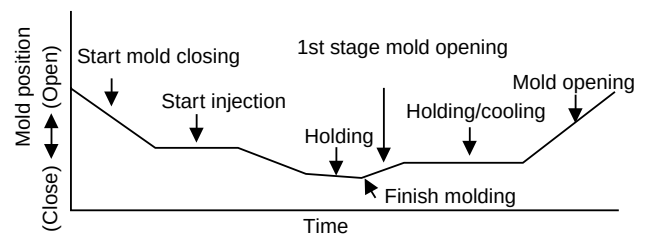


Fig.5 Molding cycle

Since the conditions of the initial mold opening have a considerable effect on the molded product, the molding conditions were checked. The expansion ratio, sheet thickness, skin layer thickness and other parameters vary according to the position of the mold at the start of opening, the initial mold opening velocity, the mold holding time, etc. For example, if the amount of mold opening at the start of injection is 20-30 mm and the mold holding time is increased, the thickness of the skin layers increases and the

foaming layer is not adequately foamed as a result of the resin temperature failing to rise sufficiently. This results in decreased thickness of the product sheet. In addition, if the final molding time after injection is decreased, the thickness of the skin layers decreases. Since this results in the foaming layer undergoing adequate foaming, the product sheet thickness increases.

3.2.2. Effect of the Initial Mold Opening

The conditions of the initial mold opening on the foaming status were investigated, and the effects of the initial mold opening velocity on the skin layer thickness and foam cell diameter are shown in Figs. 6 and 7. Tests were conducted at velocities of 0.5 mm/sec and above. It was determined that as velocity was increased, the skin layers became thinner and the foam cell diameter increased. As the mold opening velocity increased, the surface layer of the resin was unable to keep up with the movement of the mold, and a void was formed between the mold and the resin surface layer. This

void caused the pressure to decrease which in turn facilitated foaming. This resulted in the foam cells becoming larger. However, if the mold opening velocity was too high, the foam cells began to rupture, preventing the formation of a closed cell foam. In contrast, if the mold opening velocity was too slow, the mold and resin surface layers remained in constant contact, making the skin layers start to solidify and become too thick.

Next, the effects of the mold holding time are shown in Figs. 8, 9 and 10. If the holding time exceeded a certain predetermined time, the skin layers became thick and the expansion ratio decreased. As a result, foaming was inhibited and the product sheet thickness decreased. If the skin layers became excessively thick, the resin temperature in the foam layer fell and foaming was unable to adequately proceed. Therefore, a mold holding time of 1-2 seconds was determined to be most favorable.

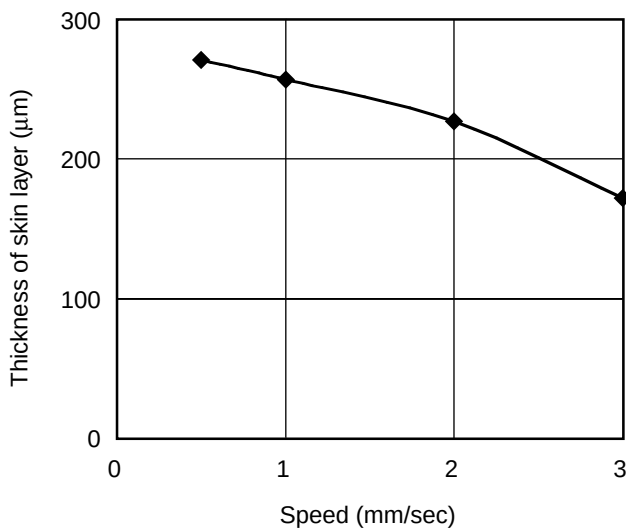


Fig.6 Initial mold opening speed and thickness of skin layer

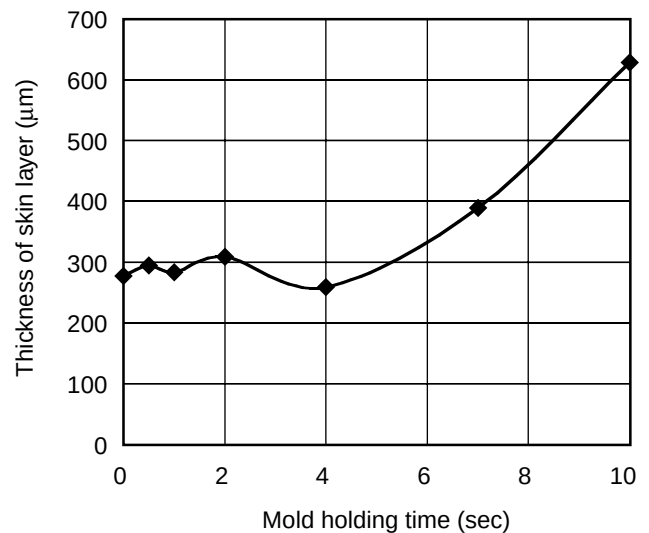


Fig.8 Mold holding time and thickness of skin layer

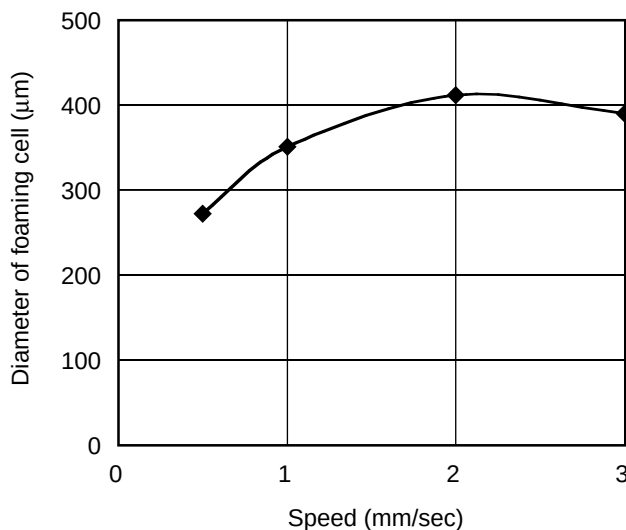


Fig.7 Initial mold opening speed and foam cell size

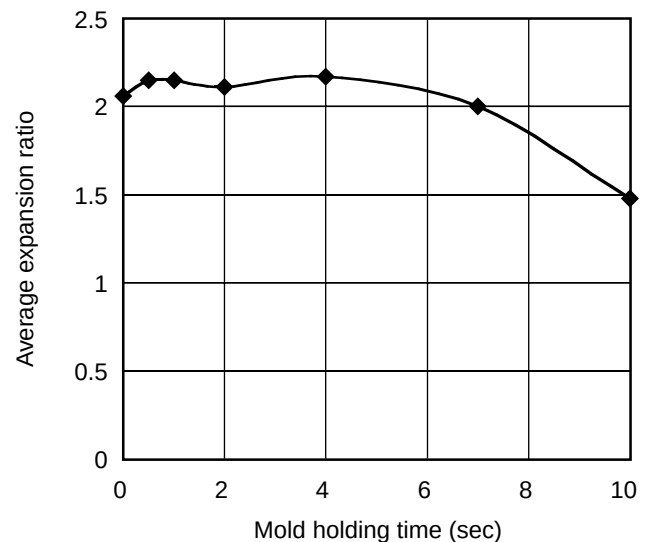


Fig.9 Mold holding time and foaming expansion

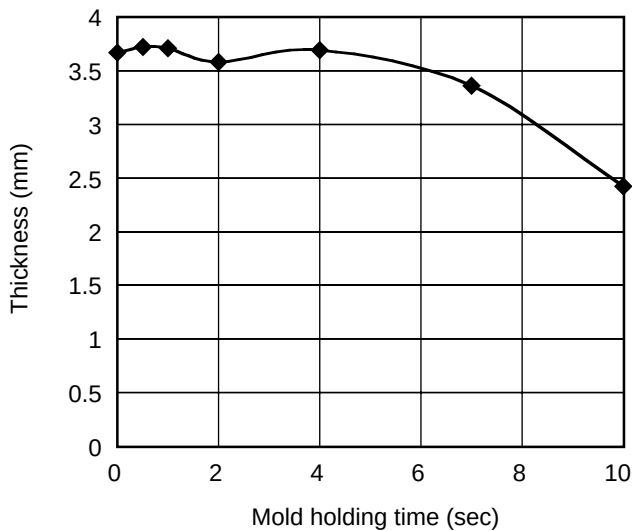


Fig.10 Mold holding time and product thickness

3.2.3. Fabric Application Conditions

Door trim employing this newly developed foamed PP resin is applied at the same time as the fabric. Therefore, the effect of fabric application on the foaming status was investigated. In the case of fabric application with ordinary injection compression molding, if the fabric is damaged by the resin heat and pressure, those fibers that are originally upright are pushed down, resulting in a dull appearance. In the case of foaming injection molding, however, it was found that damage to the fabric was less severe due to the occurrence of the initial mold opening performed immediately after the injection process, thereby proving the advantages of the process.

In addition, since the fabric is placed between the resin and mold, no well-defined skin layer is formed on the movable mold side. However, the resin impregnates the fabric to serve as a substitute skin layer, so the stiffness is maintained. Fig. 11 shows a cross-sectional photograph of a fabric-applied product. The solid layer of resin that has impregnated the fabric can be seen.

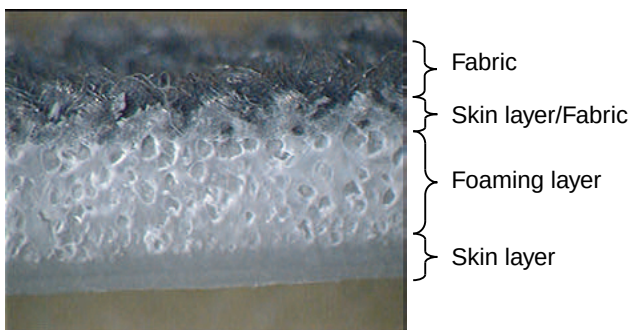


Fig.11 Cross section of product

4. Component Performance

4.1. Stiffness

Various stiffness tests were conducted on door trim that had been injection molded with foamed PP. There were no particular concerns and the product performance was satisfactory.

The amount of deflection at various locations was determined in a static load test. The results of measuring with a 30 mm diameter pressing tool supporting a weight of 10 kg indicated that standards were achieved at all locations measured. A load was also cyclically applied in the vertical direction to the armrest and the breaking load was measured. The required standard was satisfied in all cases. Since foaming does not take place on vertical surfaces with foaming injection molding, stiffness is comparable to that of the solid product.

4.2. Impact Resistance

A 1 kg steel ball was dropped from a height of 30 cm on to door trim installed on a door panel in a low-temperature environment (-30°C), which is considered to represent the extreme conditions to which the automobile will be subjected. A subsequent evaluation revealed no splitting or cracking of the door trim, confirming that the impact resistance performance was equal to that of conventional products.

In addition, no cracking or splitting of the base material was apparent in side collision tests, so the requirements were satisfied.

4.3. Confirmation of the Deformation Behavior due to Environmental Temperature Conditions

The effect of environmental temperature changes on the foamed base material was also investigated. The test consisted of 5 cycles of hot (4 hours at 80°C), cold (4 hours at -30°C), humid (4 hours at 50°C and 95% RH) and cold (4 hours at -30°C). Although a maximum gap of 1 mm occurred when the base material was returned to room temperature after completing the 5 cycles, this was determined to not present any concerns in terms of product appearance, and there was no deformation or any other apparent issues. In addition, since no secondary foaming or any other phenomena was apparent following injection molding, the foamed base material was determined to satisfy the required level of performance for use as a door trim base material.

5. Conclusions

We developed a foamed PP material for application as door trim base material as a part of the program for reducing vehicle weight. Material development included an examination of the foaming agent blending ratio and improvement of the impact resistance of the PP resin used as the base material for injection molding. Studies were also conducted on production engineering to establish a method for foaming injection molding. The following results were obtained during the course of this development:

- (1) An endothermic foaming agent prepared in the form of master batches allowed uniform foam cells to be

produced with an expansion ratio of 2.

- (2) Thin sheets of PP resin for base material injection molding could be molded by increasing the fluidity of the mix.
- (3) The addition of an elastomer in a later step at a rate of 10-20% restored the impact resistance that had been decreased by the fluidity requirement.
- (4) Products foamed to roughly twice their volume had stiffness equal to that of filled PP.
- (5) The conditions for the initial mold opening were determined to have an important effect on the expansion ratio, skin layer thickness and sheet thickness.

Vehicles in which door trim base materials produced from this newly developed foamed PP resin showed a weight reduction of 400 g per vehicle. This represents a weight savings of approximately 25% as compared with filled PP.

6. Acknowledgments

The author expresses his deep appreciation to those persons involved in conducting this development study at Japan Polychem Co., Ltd. and Nissen Chemical Co., Ltd. for their immense cooperation in examining modifications to the resin materials, producing prototype parts and numerous other activities.

7. References

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■ author ■



Kenji HIKITA