

Development of Water- and Oil-repellent Fabric Considering Durability of Automotive Seat Fabric

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ABSTRACT

In order to enhance vehicle usability, seat fabric material was developed that can easily be wiped off and resists staining even by oil from fried foods, snack foods, and other such substances, as well as from mayonnaise and other such oily foods.

The main focus in the past was to increase water repellency by applying a type of fluororesin to fibers by means of a dipping process. Now three types of fluororesin in an appropriate compound have been newly added to the dipping process, and one of those types is also applied to the back of the fabric in a back-coating process. This has made it possible for automobile interior materials to maintain water- and oil-repellency even in the high-temperature environments they are exposed to and following the abrasion caused by occupant entry and exit.

1. Introduction

In recent years, importance has been placed on comfort in the interior of automobiles viewed as personal cars, and with the expansion of the share-car business⁽¹⁾, the automobile interior has been taking on increasing importance. Car seats also have contact with vehicle occupants and can contribute greatly to enhancing comfort. Seats are being mass-produced using fabrics with deodorizing, anti-allergen, and anti-virus finishes⁽²⁾, etc.

As the needs for enhanced comfort in seat fabric materials are expanding, a study was conducted of the functions sought in car seat fabrics by users in Japan, China, Thailand, and the United States.

The study was conducted on male and female private car owners aged 20 years and over, with approximately 600 study subjects in each country. Figure 1 shows the results. Given such items as protection from soiling, reduction of stuffiness and stickiness, deodorizing, protection from scratching, and so on, it was found that the greatest needs expressed in every country were for ease in wiping off dirt and protection from spilled food and drinks.

At present, most automobile manufacturers are generally utilizing water-repellent fabrics as a performance material to deal with spilled food and drinks. In comparison with non-processed fabrics, drinks and other such aqueous liquids are less likely to stain and spills are easier to wipe up. Oils, however, are more likely to stain and tend to readily permeate the fabric. Due to the structure of the car seat, when soiling of this kind permeates to the back side of the fabric, it can permeate as far as the wadding

urethane, cover, and seat cushion pad⁽³⁾. Such stains are not readily removed, and can also become a source of odors. In light of enhanced usability, therefore, it was reasoned that adding the ability to deal with oil stains from fried foods, snack foods, and so on, as well as soiling from mayonnaise and other such oily foods, would contribute to enhanced comfort.

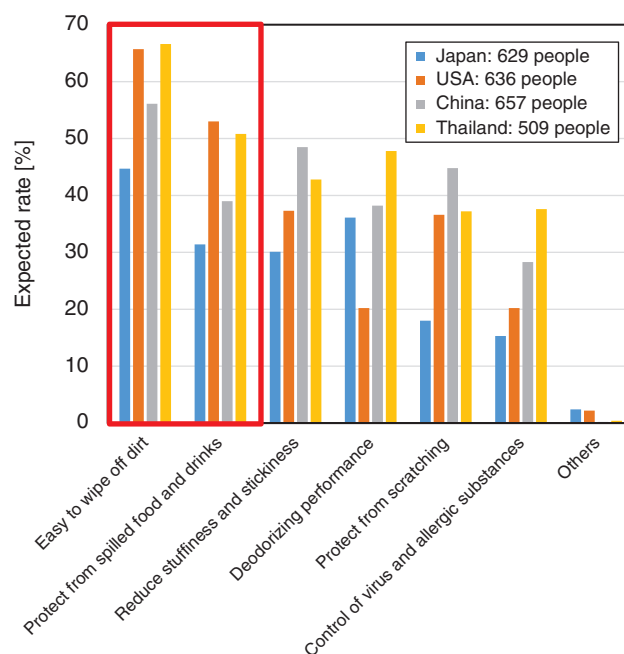


Fig. 1 Expected functions for car seats

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It is also the case that when car seat fabrics are exposed to high-temperature environments, they are simultaneously subjected to abrasion from occupant entry and exit. Durability with respect to these factors thus also needs to be taken into account, as well as the needs for external appearance and other such features that are required of automotive seat fabrics.

Given the above background, the present research aimed to enhance comfort in the car interior through development of water- and oil-repellent seat fabrics that can satisfy the basic performance desired for seat materials by providing for durability against abrasion in a variety of scenarios of high temperatures and occupant entry and exit, while still resisting staining from spilled food and drink that may adhere to the fabric, and allowing spilled matter to be easily wiped up.

2. Conceptual Approach to Target and In-house Evaluation Criteria

As the Japanese Industrial Standards (JIS) include no test methods or technical standards for fibers being soiled by food and drink, an investigation was made of test methods and target values for confirming that a developed product would repel soiling, resist staining, and be easily wiped off. This involved more than just configuration of initial values, and extended also to the performance sought for seat fabrics in terms of durability following heat aging, heat and humidity aging, and abrasion.

2.1. Settings for Types of Soiling

The types of soiling to be covered when testing performance were established in accordance with results from a study of types of soiling from foods and drinks that can adhere to car seats. The study was conducted with 43 Honda employees as subjects. Examples of the substances tested were chocolate, potato chips and other such snack foods, Worcestershire sauce, mayonnaise and other such condiments, and tea, coffee and other drinks. The general categories of components in types of food and drink stains are shown in Fig. 2.

Based on the previously described results, the following were set as representative substances for the various types of stains: For aqueous liquid stains, Worcestershire sauce was chosen because the distinct staining caused by its

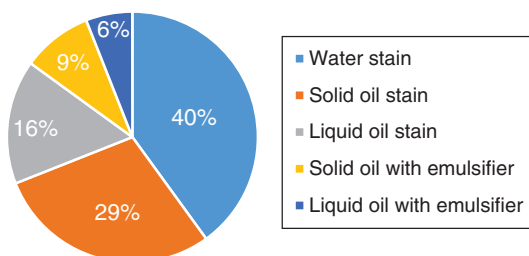


Fig. 2 Types of stains (foods and drinks)

Table 1 Typical stains adhered to seat

Classification	Target stain
Water stain (dark color)	Worcestershire sauce
Solid oil stain + Protein	Mayonnaise (sandwich, hamburger)
Liquid oil stain	Salad oil (potato chips)
Solid oil and emulsifier	Chocolate
Liquid oil and emulsifier	Coffee cream

Table 2 Requirements of water- and oil-repellent performance

Test item			Requirement
Water- and oil-repellent	Water- and oil-repellent (for foods)	Initial state	Contact angle between stain and test piece is over 90°
	Water-repellent (for drinks)	Initial state	Grade 4 min.
		· After heat aging · After heat and humid aging · After abrasion	Grade 3 min.

dark color can be easily discerned; for solid oil stains, the substance chosen was mayonnaise, which includes oil and protein; and for liquid oil stains, the substance chosen was salad oil, which is used in snacks and other foods. For staining by a solid oil with an emulsifier, chocolate was chosen, as temperature changes cause it to become a liquid; and for staining by a liquid oil with an emulsifier, the substance chosen was coffee cream (Table 1). Ordinary products from specific manufacturers were chosen for each type of stain.

2.2. Fabric Standalone Performance

2.2.1. Water- and oil-repellency

Regarding water- and oil-repellency, it was confirmed that a fabric will generally repel the soiling substance when the contact angle between the fabric and the substance causing adherence is 90° or greater⁽⁴⁾. The test was therefore configured so that the food and drink items in Table 1 would adhere to the fabric with a contact angle between stain and test piece of 90° or greater. Regarding water repellency with respect to soiling by drinks, the “Testing methods for water resistance of textiles” in JIS L 1092 (2009) that are also configured for use with conventional water-repellent fabrics were taken as a basis. The initial target value was set at Grade 4 or higher, and the value after aging at Grade 3 or higher. Table 2 shows Requirements of water- and oil-repellent performance.

2.2.2. Resistance to permeability to the back side

Resistance to permeability to the back side defines resistance to staining, and high-temperature states were taken into account to address users who only drive on

Table 3 Requirements of permeability to fabric back side

Test item		Requirement
Permeability to fabric back side	Initial state	No penetration to back side
	· After heat aging · After heat and humid aging · After abrasion	No penetration to back side

Table 4 Requirements of wipeability

Test item		Requirement
Wipeability	Initial state	After wet wipe: Grade 4 min.
	· After heat aging · After heat and humid aging · After abrasion	After wet wipe: Grade 3 min.

weekends and cause soiling substances to adhere to the fabric during high summer, only noticing it a week later. Target values were set so that the substance would not stain the fabric completely even in these conditions.

Testing employed the five types of stain substances in Table 1. The accelerated test conditions used to confirm the influence of high temperatures were set at 80°C × 24 h. This was calculated from the actual vehicle temperature measurement data obtained by the thermal history concentration method⁽⁶⁾ that employs Arrhenius plots and that is also used with rubber and organic materials. The objective was for the fabric to resist allowing the stain to permeate to the back side, even after leaving a substance on the fabric for the prescribed period, thereby staining it. Table 3 shows the Requirements of permeability to fabric back side.

2.2.3. Wipeability

In order to confirm wipeability, methods of wiping substances off the fabric were defined (Fig. 3). Dry- and wet-wipe methods were chosen since these obtained

approximately 80% responses in an in-house questionnaire survey. First, a soiling substance was dripped onto the fabric and a dry wipe was used without pressing to avoid the substance physically infiltrating the structure of the fibers. If any soiling remained after the substance was wiped off, a wet wipe was used with a tapping motion. The “Grey scale for assessing staining” in JIS L 0805 (2005)⁽⁷⁾ was then used to evaluate the differing intensity of staining once the above methods were used to wipe off the fabric following application of the test conditions described in Clause 2.2.2. Generally, a difference in stain intensity that users can easily perceive will be classified under Grade 3, so the target value for the fabric after durability aging is defined as Grade 3 or higher, while the initial value is defined as Grade 4 or higher. Table 4 shows the Requirements of permeability to fabric back side.

2.2.4. Basic performance of fabric

Together with providing water- and oil-repellency, resistance to permeability to the backside, and wipeability, the developed product was defined as having the strength characteristics, color fastness, and other such elements of basic performance required of car seat fabrics equal to or at a higher level than non-processed products. Table 5 shows the performance items and test methods.

2.3. Seat Assembly Performance

2.3.1. Manufacturability of seat assembly

When utilizing the fabric material in seat assembly, it is important to maintain manufacturability and appearance for good product appeal. Generally, fabrics become harder when coated with processing agents, so various items were defined for confirmation. These include checking whether water- and oil-repellent fabrics have developed wrinkles typical of such materials, whether the steam applied during manufacturing has caused steam marks to be left as white traces, whether the sewing process has left visible needle holes, and so on.



Fig. 3 Test method of wiping off

Table 5 Test items for basic performance of seat fabric

	Items	Test methods
Basic items	Constant elongation	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
	Tensile elongation	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
	Tearing strength	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
Concern items	Electrification property	JIS L 1094 Testing methods for electrostatic propensity of woven and knitted fabrics ⁽⁹⁾
	Flammability	FMVSS Flammability of Interior Materials ⁽¹⁰⁾
	Color fastness	JIS L 0849 Test methods for color fastness to rubbing ⁽¹¹⁾
	Light resistance	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
	Heat resistance	Color change of test piece after standing at 110°C for 200 hours is judged using gray scale
	Heat and humidity resistance	Color change of test piece after standing at 50°C /95RH for 500 hours is judged using gray scale

2.3.2. Seat assembly durability performance with respect to entry and exit

Seat assembly durability performance with respect to entry and exit was verified by checking appearance for good product appeal, permeability to the back side, and wipeability of the product. Durability testing with respect to entry and exit comprises testing of the seat assembly using a robot with a dummy of a vehicle occupant's buttocks. The test involves the robot repeating the back-and forth actions for entry and exit mode. As to appearance for good product appeal, the objective was defined as not having any visible deposits of resin, unusual abrasions, or other such issues. To verify resistance to permeability to the back side and wipeability, portions of the seat fabric were removed from the seat assembly after durability testing for entry and exit. The objective for the seat fabric was to satisfy the target value for abrasion durability after applying salad oil, which was chosen from the five stain types shown in Table 1 because of its lower surface tension.

3. Basic Specifications of Water- and Oil-Repellent Fabrics

3.1. Conventional Water-Repellent Fabric Specifications and Issues for Water- and Oil-Repellent Fabric Material

Water- and oil-repelling performance produces its effect by means of fine cilia such as those found on lotus leaves and peach skins, and from chemical action that produces its effect by a coating of chemical agents⁽⁴⁾. For the present development, it was decided to adopt chemical action because it imposes fewer constraints on the design and

can continue to provide performance even after testing for durability with respect to entry and exit.

The reasons why coating with chemical agents yields performance are given as follows. When a droplet of liquid (water, oil, etc.) placed on the surface of a solid forms contact angle θ , the surface tension γ_L of the droplet, the surface tension γ_s of the solid surface, and the interaction γ_{LS} between the solid and the droplet are described by Young's equation⁽⁴⁾ as shown in Eq. (1).

$$\gamma_s = \gamma_L \cos\theta + \gamma_{LS} \quad (1)$$

$$\cos\theta = (\gamma_s - \gamma_{LS}) / \gamma_L \quad (2)$$

Equation (1) can be converted into Eq. (2), which shows that when the surface tension of the solid is lower than that of the liquid, the lower it is the greater the contact angle will be, thereby yielding repellent performance. Consequently, silicone resin with the CH_3 group and fluororesin with the CF_3 group that have low surface tension can be cited as prime examples of agents for chemical action. However, since the CF_3 group has lower surface tension than the CH_3 group, the same fluororesin used in conventional water-repellent fabric was investigated. Figure 4 shows an example of a fluororesin array on a fiber. Thus, the main chain of adhesive polymer adheres to the fiber and the fluororesin side-chain yields water- and oil-repelling performance.

Conventional water-repellent fabric is coated by dipping it in a fluororesin of one type that has a hydrophilic group. Figure 5 shows the structure of conventional water-repellent fabric material. Fluororesin is distributed over the entirety of the fabric fibers and is fixed on it by the dipping process.

However, even though this material specification yields satisfactory water repellency, oil has lower surface

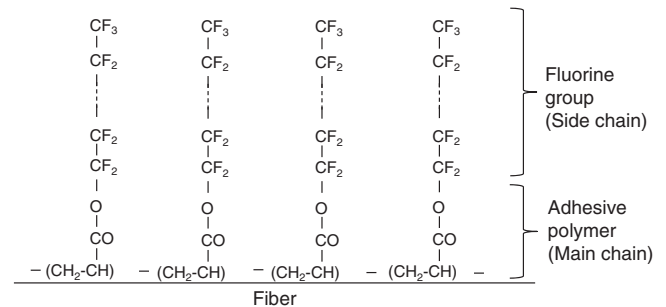


Fig. 4 Array of fluororesin on fiber

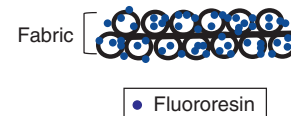


Fig. 5 Structure of conventional fabric

tension than water and so this specification does not yield the objective of satisfactory oil repellency. Furthermore, if larger amounts of fluororesin are coated than that coated on conventional mass-produced water-repellent fabric in order to yield satisfactory water- and oil-repelling performance, then when the fabric is scratched by a fingernail or other such object, it will leave visible white traces known as chalk marks and will reduce electrification and flame resistance. These are examples of how this would be counterproductive.

Measures were devised regarding fabric structure and selection and compounding of a type of fluororesin in order to yield satisfactory target values while also resolving these issues. In order to remove the water- and oil-repelling performance rooted in physical action by cilia from the fabric used for verification, the testing was conducted with non-raised tricot fabric.

3.2. Selection and Compounding of Fluororesin for Use in Dipping Process

The fluororesin (Type A) with a hydrophilic group that is used in conventional water-repellent fabric material, as described in Section 3.1., has the advantage of achieving a simultaneous balance with electrification. It also has the characteristic, however, that physical impact and thermal load can cause the orientation to become disordered so that water- and oil-repelling performance is reduced (Fig. 6).

Fluororesins of various types were therefore selected. First, for the main chain, an adhesive polymer of a high glass transition point (T_g) type was arranged and a fluororesin (Type B) was selected that, by rigidifying the

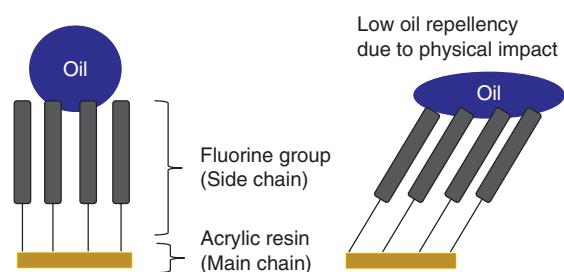


Fig. 6 Image of chemical structure of fluororesin

Table 6 Test results of one kind of fluororesin

Percentage of fluororesin (%)	Type A	100	0	0
	Type B	0	100	0
	Type C	0	0	100
Concern property items	Permeability to fabric back side	–	+	–
	Water-repellent (Test result)	+(Grade 5)	–(Grade 3)	+(Grade 4)
	Chalk mark	–	–	–

+ : Acceptable
– : Unacceptable

main chain, causes the orientation of the side-chain fluorine group to be less susceptible to becoming disordered and enhances water- and oil-repelling performance. When the polymer changes from a liquid to a solid, it goes from a rubber state in which the molecules move easily to a glass state in which the movement of the molecules is limited. T_g is the temperature at which it changes to this glass state, and a type with a higher T_g exists in a higher temperature range when in a glass state. Thus, the main chain rigidifies even when the interior temperature reaches a high level, making the orientation of the side-chain fluorine group less susceptible to becoming disordered.

Next a fluororesin (Type C) was selected that has an adhesive polymer main chain with a lower T_g than Type B and that therefore limits the hardness of the fabric after processing. Figure 7 shows a schematic illustration of the selected fluororesin and their features. Table 6 shows the results for initial resistance to permeability to the back side by salad oil when left standing after exposure to $80^\circ\text{C} \times 24$ h, initial water repellency, and chalk mark with test pieces each coated with just one of the Type A, Type B, or Type C fluororesins. As this indicates, the desired performance could not be satisfactorily realized with just one kind of fluororesin.

In order to meet all the target values, therefore, an investigation was made into compounding three kinds of fluororesin and adjusting their proportions.

Table 7 shows the results for initial resistance to permeability to the back side by salad oil when left standing after exposure to $80^\circ\text{C} \times 24$ h, initial water repellency, and chalk mark with Type A, Type B, or Type C in varying proportions.

Type of fluororesin		
Type A	Type B	Type C
Fluorine group Acrylic resin Hydrophilic group	Fluorine group Acrylic resin (high T_g)	Fluorine group Acrylic resin (low T_g)
Control electrification performance by hydrophilic group	Advanced oil repellent performance by high T_g	Control hardness of fabric by lower T_g than Type B

Fig. 7 Features of fluororesin

Table 7 Test results with varying proportion of fluororesin

Percentage of fluororesin (%)	Type A	95.2	52	25	0
	Type B	4.8	2	0	4.8
	Type C	0	46	75	95.2
Concern property items	Permeability to fabric back side	+	+	−	+
	Water-repellent (Test result)	− (Grade 3)	+	+	− (Grade 3)
	Chalk mark	−	+	+	−

+: Acceptable
−: Unacceptable

The results show that chalk mark results are unacceptable unless the Type B fluororesin is in a low proportion, but unless some Type B is included in the compound, the oil repellency cannot meet the target value. It was also found that including just two kinds would not achieve satisfactory results. By observing the balance of the three kinds of fluororesin in this way, the optimal compounding proportion was ascertained.

3.3. Optimization through Treatment Process

Even when the three kinds of fluororesin have been compounded, treatment by the dipping process alone results in variations in water- and oil-repelling performance because the pattern in the seat fabric has raised and recessed portions, and the increased amount of resins reduced flame resistance. Another factor is that each treatment process involves a drying process to fix the dye and chemical agent to the material, adding to the thermal history, which was found to become an issue for color fastness due to sublimation of the dye. These issues were resolved by optimization of the treatment process.

3.3.1. Performance stabilized by back-coating process

In order to limit variations in water- and oil-repelling performance and reduction in flame resistance, a process of back coating with fluororesin (Type A) that includes a hydrophilic group as well as a flame retardant was applied to the back side of the fabric. Ordinarily, back coating is used to apply a coating of flame retardant, but in this case, the addition of fluororesin successfully stabilized the material's oil-repellency and resistance to permeability to the back side. Also, as shown in Fig. 8, treating the material with fluororesin using a combination of dipping and back coating provided stable, satisfactory water- and oil-repelling performance regardless of fabric pattern.

3.3.2. Maintaining color fastness by addition of washing process

Since the addition of the back-coating process caused the drying process to increase, the resulting increase in the thermal history made color fastness an issue. Consequently, it became necessary to remove excess dye so that the target values for color fastness could be met even in the case of darker-colored fabric that contains larger amounts of dye, and a washing process was added after the dipping process. Figure 9 shows the developed treatment process.

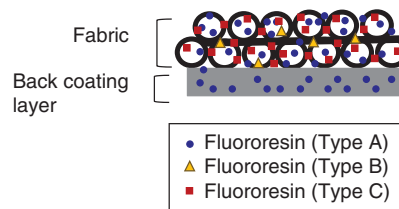


Fig. 8 Fabric structure

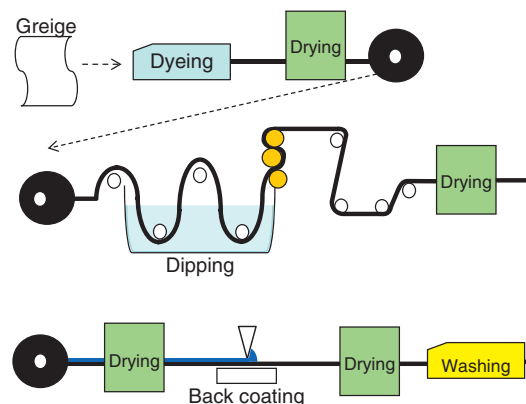


Fig. 9 Process of chemical compound treatment

4. Results of Performance Tests

4.1. Fabric Standalone Performance Results

Tables 8 through 10 show the results for the in-house evaluation criteria defined for the water- and oil-repellent fabric developed here. As indicated, all target values were confirmed to have been satisfactorily achieved. The results for the developed product also compare favorably with non-processed products in terms of the basic performance sought in car seat fabric, and the fabric standalone performance satisfactorily meets all of the in-house evaluation criteria.

Figure 10 shows the comparative results for initial

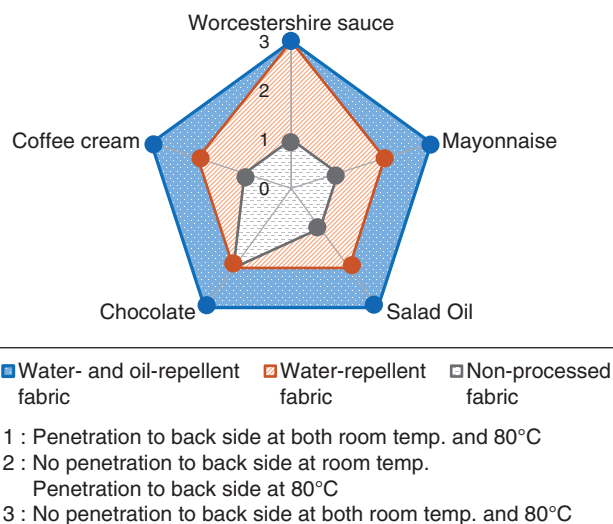


Fig. 10 Comparison of permeability

Table 8 Test results for water- and oil-repellent performance

Test item		Requirement	Test result	Judgement
Water- and oil-repellent	Water-repellent (for drinks)	Initial state	Grade 4 min.	Acceptable
		· After heat aging · After heat and humid aging · After abrasion	Grade 3 min.	
	Water- and oil-repellent (for foods)	Initial state	Contact angle between stain and test piece is over 90°	

Table 9 Test results for permeability to fabric back side

Test item		Requirement	Test result	Judgement
Permeability to fabric back side	Initial state	No penetration to back side	None	Acceptable
	· After heat aging · After heat and humid aging · After abrasion	No penetration to back side	None	

Table 10 Test results for wipeability

Test item		Requirement	Test result		Judgement
Wipeability	Initial state	After wet wipe: Grade 4 min.	Worcestershire sauce 4 Mayonnaise 4 Salad oil 4 Chocolate 4 Coffee cream 4		Acceptable
	(1)After heat aging (2)After heat and humid aging (3)After abrasion	After wet wipe: Grade 3 min.	(1)	Worcestershire sauce 4 Mayonnaise 3.5 Salad oil 4 Chocolate 4 Coffee cream 3	
			(2)	Worcestershire sauce 4 Mayonnaise 3.5 Salad oil 4 Chocolate 4 Coffee cream 4	
			(3)	Worcestershire sauce 4 Mayonnaise 4 Salad oil 3.5 Chocolate 4 Coffee cream 4	

permeability to the back side of the fabric by the five types of stain substances applied to water- and oil-repellent fabric, mass-produced water-repellent fabric, and non-processed fabric materials after standing for 24 hours at room temperature and at 80°C. When a colored background covers a larger area, this means the corresponding fabric is displaying increased water- and oil-repelling performance.

The non-processed fabric material was permeated by every type of stain substance except chocolate at room temperature and at 80°C. The mass-produced water-

repellent fabric material was not permeated at room temperature, but it was permeated at 80°C by every type of stain substance except Worcestershire sauce. In contrast with these, the water- and oil-repellent fabric material showed no permeation by any of the stain substances either at room temperature or at 80°C.

Further results confirming permeability by salad oil at an initial 80°C are shown as a representative case in Fig. 11. This confirms that the developed product possesses oil-repellency.

In addition to the test with salad oil, performance was confirmed by placing fried chicken, which tends to exude oil, on water- and oil-repellent fabric and non-processed fabric materials. Figure 12 shows the results. The non-processed fabric developed stains soon after the chicken was placed on it, but oil stains were not seen on the water- and oil-repellent fabric even after leaving the chicken on it for seven days.

4.2. Seat Assembly Performance Results

The developed product was also confirmed to have satisfactorily achieved all the objectives for manufacturability of the seat assembly. The results for seat assembly performance after aging for durability with respect to entry and exit described in Clause 2.3.2. are shown in Fig. 13. The developed product was successfully confirmed to have satisfied the item regarding seat assembly performance after aging for durability with respect to entry and exit.

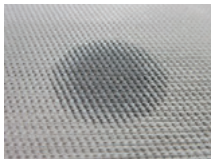
	Water- and oil-repellent (developed item)	Water-repellent (mass production)	Non-processed
Salad oil			
Results	Oil-repellent	Penetrate	Penetrate

Fig. 11 Comparison of developed material

	Water- and oil-repellent (developed item)	Non-processed
	After one week	After 5 seconds
Fried chicken		
Results	Oil-repellent	Penetrate

Fig. 12 Result of placing fried chicken

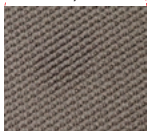
Test items	Requirements	Results
Ingress and egress durability (10000 cycles)	· No unusualness such as wrinkles · No tear of fabric	Acceptable 
Permeability and wipeability after ingress and egress durability test	· No penetration to back side · After wet wipe: Grade 3 min.	Acceptable (Grade 3.5) 

Fig. 13 Results of ingress and egress durability test

5. Conclusion

In the present research, water- and oil-repellent fabric was developed that is readily wipeable and resists staining from food and drink containing oil that adhere to car seat fabrics even in the high temperatures to which such material is exposed, and even after providing for durability against abrasion.

- (1) Three types of fluororesin in appropriate compounding proportions were applied in a dipping process and one type of fluororesin was applied in a back-coating process. With these specifications established, the treated materials displayed water- and oil-repellency in high temperatures and following abrasion. This approach also satisfied the need for the seat assembly to realize an appearance for good product appeal.
- (2) By adding a washing process to follow fluororesin dipping, the need for color fastness was satisfied and stable production processes were established even for material with varying gradations of color.

The water- and oil-repellent fabric developed through the present research was applied in the 2020 model year STEPWGN. The technology for providing seat fabric with added functionality is expected to have expanded applications for these seats not only in automobiles but also in buses, trains, and so on, as well as in upholstery for sofas and other such applications where the fabrics cannot be laundered.

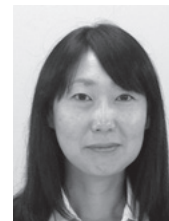
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