Friction Characteristics of Fabrics with Air

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High frictional force between the skin and air bag greatly influences the scratch damage to human skin when an air bag inflates and rubs against the skin. The coefficient of friction should therefore be reduced. In this study, we proposed a new method to reduce frictional force by producing air lubrication between an air bag made of non-coated fabric and human skin. Air was generated, and an experimental device that could measure frictional force was produced. The frictional force of the air bag with air was measured, and effectiveness and efficiency were confirmed. In the presence of air, the friction disk materials, fabric materials, and fabric structure do not influence the frictional force and coefficient of friction. Instead, the coefficient of friction is influenced by air mass flow passing through the fabric.

Keywords: Friction, Fabric, Airbag, Evaluation, Mechanical properties, Air

1. INTRODUCTION

Air bag systems used as collision safety devices for automobiles effectively reduce the number of deaths in traffic accidents. Thus, side air bags and curtain air bags for automobiles have been developed and put into practical use. Air bags for motorcycles and air bags to protect pedestrians have also been developed. To investigate the buffering effect of air bags inflated in a car at the time of an accident, we focused on the impact force when the air bag contacted the driver, devised a test apparatus by modeling the air bag and the driver, measured and simulated the impact force under various contact conditions, and examined mechanisms of buffering as well as influence factors (BAO, SAIJO, QIAN, TAKATERA, & KEMMOCHI, 2008). Fukaya (FUKAYA, 2003) confirmed the buffering effect of air bags for protection against crashes.

However, injuries (e.g., bruises and scratches) caused by inflation of air bags have been reported (SIMAMURA, 2000; OYAMA, 1998; ARAI, TATEISHI, 2002). Therefore, we proposed a method for measuring and simulating the impact force caused by high-speed inflation of an air bag, and clarified the relationship between impact force and the dynamic characteristics of air bag fabric, as well as influence factors using such a method (BAO, SAKURAI, & KEMMOCH, 2006; BAO, TAKATERA, & KEMMOCHI, 2007). It was assumed that scratch damage is caused by inflation of the air bag as follows. After inflation of the air bag (Fig. 1), the fabric of the air bag closely contacts the human body (face) due to the high pressure inside the air bag, and a large frictional force is generated between the fabric and skin, scratching the skin. We assume that scratches can be mitigated by decreasing this frictional force.

The friction characteristics of textile materials affect the productive process of both cloth and textile goods; thus, studies of such characteristics have been conducted for many years (Schick, 1975). Various methods to reduce the coefficient of friction (e.g., changing the textile material or the texture of fabric and reforming the material surface) have been reported. The authors attempted to reduce the frictional force between air bag and skin by changing the airbag cloth or by applying surface treatment to the air bag; however, such measures had little effect and failed to reduce frictional force greatly (BAO, TAKAMASU, SAKURAI, KEMMOCH, & NAKAZAWA, 2002).

In this study, to prevent scratches when the air bag is inflated, we attempted to reduce the friction by forming an air layer utilizing the permeability characteristic of each type of fabric.
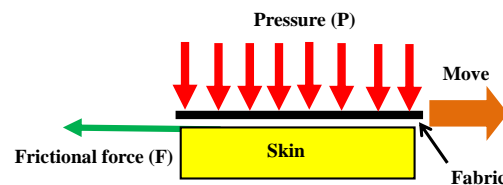

Fig. 1. Frictional scratches from an airbag

2. REDUCING FRICTION FROM THE AIRBAG

Recently, application of zero-friction technology has advanced in the field of tribology to achieve

high speed and save energy. The hard disk for computers is an example: a thin air layer between the magnetic head and the rotating disk reduces friction to achieve high speed and stability (KANEKO, 1995).

We assumed that frictional force and scratches can be greatly reduced if there is a thin air layer between the air bag and the human body in the manner described above. Here, we try to reduce the frictional force of the air bag by utilizing non-coated fabric with air permeability so that part of the air passes through the fabric under the pressure inside the air bag and forms a thin air layer between the air bag and the human skin (Fig. 2). In this study, we prepare a prototype apparatus that can form a thin air layer and measure frictional force, and then use it to measure frictional force in the presence and absence of air. The purpose of this study is to examine the reduction of frictional force by the air layer, the material exposed to friction, and the influences of air pressure and air mass flow in order to obtain data for designing air bags.
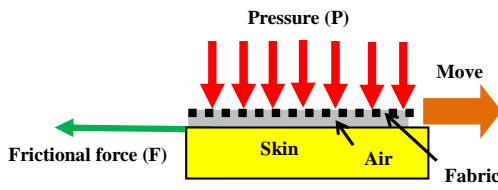

Fig. 2. Friction decrease of airbags with air

3. TEST APPARATUS AND SAMPLES
3.1 Test Apparatus and Test Method

To measure the friction characteristics of the air bag with and without air, we manufactured a prototype apparatus that can generate a thin air layer and measure friction characteristics in the presence of such a layer. Figure 3 schematically depicts the test apparatus.

The fabric for the air bag is fastened on the surface of the rotation disk connected to the pulley so that it can be turned with a motor. The rotation disk has a hole, and pressure is applied to the fabric by blowing compressed air through the hole. Air passes through the non-coated fabric to generate an air layer between the fabric and the friction disk. If the fabric is lined with 0.5mm-thick styrene film, the fabric intercepts the flow of air to represent the state of a conventional normal air bag. Rubber simulating human skin (silicon rubber, type A, hardness 36 according to JIS K6253) is fastened to the fixed disk (friction disk), and friction with the fabric is generated. A semiconductor strain gauge (Kyowa Dengyo, KSN-2) is attached to the root portion of the fixed disk to measure the torque applied to the fixed disk.

Tests are conducted according the following procedure.
1) Mount the sample fabric on the surface of the rotation disk. Bring the friction disk close to the fabric; turn the rotation disk; and carefully adjust the parallelism between the friction disk and the fabric surface so that no torque occurs in the friction disk.
2) Charge the air compressed by an air compressor into the air tank, and blow air through the hole in the rotation disk to inflate the fabric. Adjust the internal pressure of the air tank with the regulator, while measuring the air pressure inside the fabric so that the air pressure reaches the set value.
3) Turn the rotation disk and fabric at 10rpm with a motor; collect data of the torque applied to the friction disk using a torque strain gauge and a data collection system (Keyence Co., Ltd. NR-500); and store the data in a PC. The sampling interval is 20μsec.
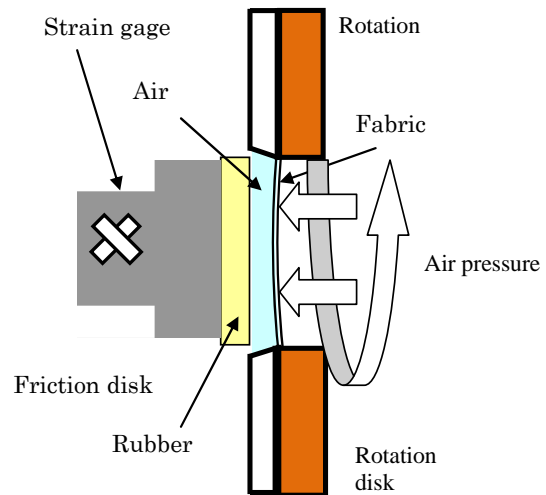

Fig. 3. Experiment apparatus for measuring friction characteristics of fabric

3.2 Calculating Frictional Force and Coefficient of Friction

Assuming that frictional force is applied evenly to the surface of the friction disk, torque (T, Nm) can be expressed by equation (1) (Fig. 4).

$$dT = f \cdot 2\pi r \cdot dr \cdot r = f \cdot 2\pi r^2 dr$$

$$T = f\int_0^R 2\pi r^2 dr = f\frac{2\pi}{3}R^3 \qquad (1)$$

Here, R represents the radius of the friction disk, and f(N/m^2) is the frictional force per unit area.

The relationship between the frictional force per unit area and the coefficient of friction can be expressed by

$$f = \frac{3T}{2\pi R^3} \qquad (2)$$

$$\mu = \frac{f}{P} \qquad (3)$$

were P[Pa] represents the air pressure applied to the surface of the fabric, which corresponds to the vertical load per unit area.
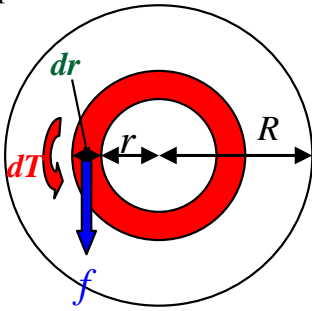

Fig. 4. Method of calculating frictional force

3.3 **Sample**

The sample fabric used in the test ((N4256) was provided by Toyota Boshoku Co., with the specifications presented in Table 1. It is non-coated, plain-woven fabric that is used in air bags for automobiles. The material is nylon 66. For comparison, polyester plain-woven fabric having similar cover factors was also used (Poly in Table 1).

Table 1 Physical characteristics of airbag fabric samples

Type No.	Material	Yarn Linear Density dtex/Filaments	Ends and Picks/inch	Weave
N4256	Nylon 66	470/72	55×55	Plain
Poly.	Polyester	350/70	66×65	Plain

4. TEST RESULTS AND DISCUSSION
4.1 Measuring Frictional Force and Coefficient of Friction

The fabric fastened at its peripheral was inflated by compressed air until it contacted the friction disk with rubber mounted on its surface. The torque caused by frictional force was measured using the device described in Section 3.1. Figure 5 depicts an example of the measurement result, which is the curve of the torque vs. time measured, with the air pressure set to 0.3MPa. The sample fabric is N4256. "Without air lubrication" corresponds to normal air bags that intercept air flow, and "With Air lubrication" is the measurement on non-coated fabric.

The average torque per turn of the disk obtained from the curve in Fig. 5 is substituted in equations

(1), (2), and (3) in Section 3.2 to obtain dynamic frictional force and dynamic coefficient of friction (hereinafter, frictional force and coefficient of friction). Figure 6 depicts the curves of frictional force, and Fig. 7 depicts the coefficient of friction of Sample N4256. The curve of the coefficient of friction of the air bag vs. air pressure in the air bag matches the normal phenomena of friction, where the coefficient of friction decreases as the pressure (which corresponds to the vertical load) becomes higher. Furthermore, frictional force is considerably lower with air than without it, and the coefficient of friction decreases to one-tenth. This indicates that frictional force can be greatly decreased by generating a thin air layer. We assume that utilization of this result will lead to considerable reduction of scratches damage during air bag inflation.
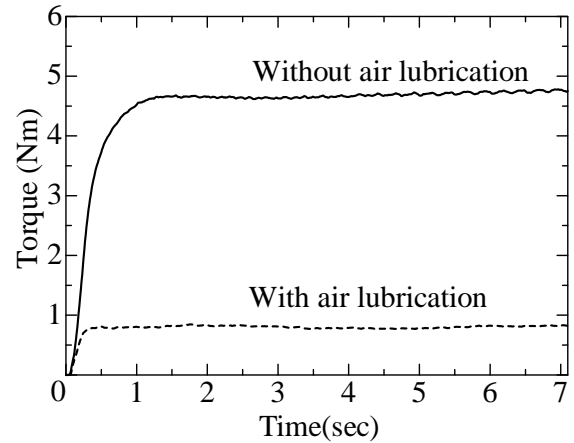

Fig. 5. Time-torque curve with and without air lubrication. (Sample: N4256. Air pressure: 0.30 MPa.)
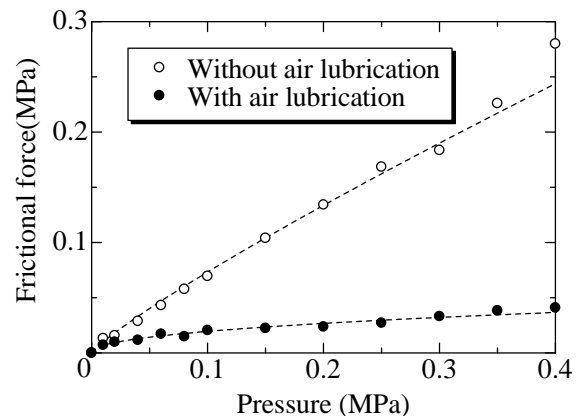

Fig. 6. Relationship between frictional force and pressure of air. (Sample: N4256. Friction disk material: rubber.)
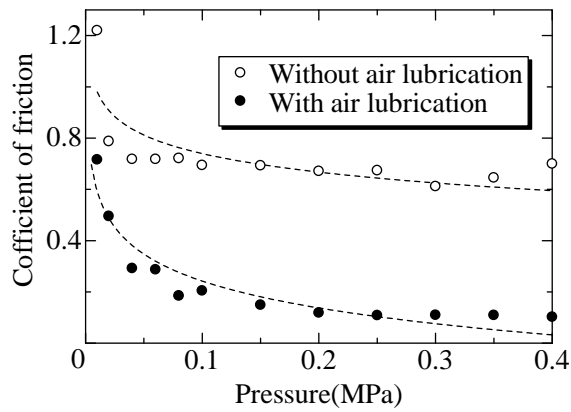
Fig. 7. Relationship between coefficient of friction and air pressure (Sample: N4256. Friction disk material: rubber.)

4.2 Influence of Friction Disk Material

The surface roughness and hardness of the friction disk greatly affect friction characteristics, including frictional force; therefore, we investigated the friction characteristics of fabric in the presence of air while changing the friction disk material.

For the friction disk, hard nylon (Plastic) and S45C steel were used, in addition to soft rubber (used in the previous section). The forms of these materials are the same as rubber with a surface roughness of Ra 1.6.
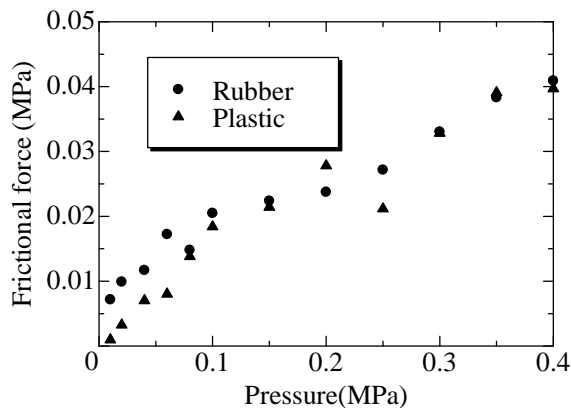

Fig. 8. Relationship between frictional force and air pressure. (Sample: N4256. Friction disk materials: rubber and plastic, with air lubrication)

Measurement indicated that friction disks made of hard nylon and S45C steel exhibited almost the same friction characteristics, regardless of the presence or absence of air; therefore, we describe here the difference between friction characteristics of the hard-nylon and rubber friction disks.

Figure 8 compares friction force with and without air. The sample used here is N4256. Unlike the case employing fabric to intercept the air flow, frictional force differs according to the difference in friction disk material. Though frictional force differs according to difference in the hardness of the friction disk at low air pressure, the difference between the curves decreases as air pressure increases, indicating no influence of the hardness of the friction disk on frictional force.
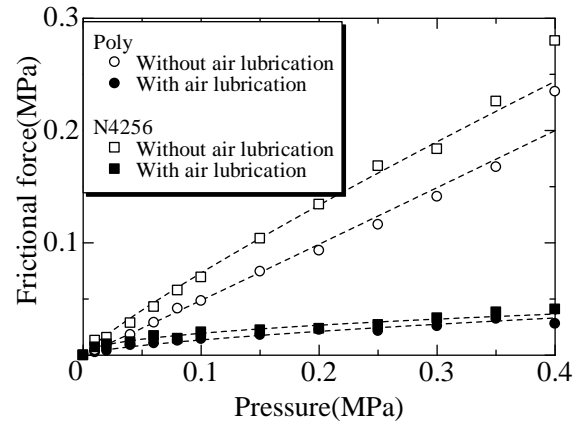

Fig. 9. Relationship between coefficient of friction and air pressure (Sample: Poly and N4256. Friction disk material: rubber.)

4.3 Influence of Fabric Type

We investigated the changes in friction characteristics with fabrics that have almost the same permeability (similar cover factor). We measured the friction characteristics of both Sample N4256 (nylon 66) and polyester fabric (Poly). Figure 9 illustrates the relationship between frictional force and air pressure. The friction disk is made of rubber, and non-permeable fabric samples were prepared by applying styrene film to the back of the otherwise permeable fabric sample. Comparing N4256 and poly indicates that while the coefficients of friction differ between the two types of fabric in the absence of air, they have almost the same values in the presence of air. While the fabric material and structure (e.g., the density of threads) largely affect friction characteristics when the friction disk contacts the fabric, we assume that contact between the friction disk and the fabric decreases when there is a thin air layer between them, and the influence of the material and structure of the fabric on friction characteristics decreases accordingly. Textbooks(PASTORE, & KIEKENS, 2001) cover many studies on the influence of materials and structures on fabric permeability; thus, we have omitted an explanation of them here.

4.4 Influence of Air Mass Flow

To investigate the influence of just the air mass that flows through the fabric, paper filters with various degrees of permeability were inserted to produce different ventilation volumes at the same internal air pressure. After comparing several

types of paper filters, we selected ADVANTEC qualitative filters No. 131 and No. 1. A measurement example is depicted in Fig. 10. The left vertical axis represents the coefficient of friction, and the right vertical axis represents the measured air mass flow. The fabric sample was NN4256, and the friction disk was made of rubber. We set the air pressure to 0.1MPa, 0.2MPa, and 0.3MPa and measured the air mass flow and coefficient of friction at each value. When paper filters were used, the coefficient of friction decreased as air mass flow increased even at the same air pressure. The coefficient of friction can be represented by a single mass flow curve regardless of air pressure. The air that passed through the fabric produced a thin air layer between the fabric and friction disk, and the frictional force and coefficient of friction were reduced greatly by air lubrication. We assume that as the air mass flowing through the fabric increases, the air layer acting as air lubrication becomes larger and reduces frictional force. However, the state of contact between the fabric and the friction disk in the presence of air and the thickness of air layer are unknown; these issues need further examination in the future.
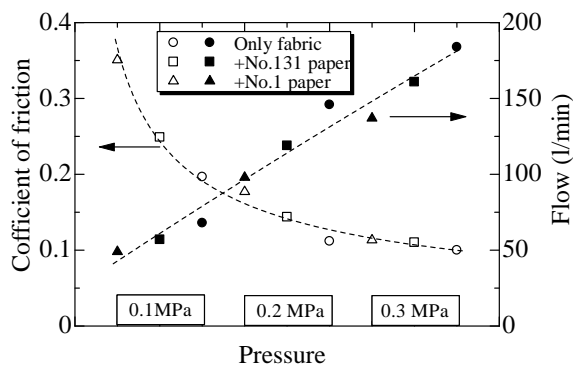

Fig. 10. Relationship between air flow and coefficient of friction (Sample: N4256. Friction disk material: rubber.)

5. CONCLUSION

To reduce the frictional force between the air bag and skin, which greatly influences the scratching caused by inflation of the air bag, we proposed a method for reducing frictional force. A permeable air bag that utilizes non-coated fabric was adopted to produce an air layer between the air bag and human skin. To verify the effect of this method, we manufactured a prototype apparatus that can produce an air layer and measure frictional force, and then measured frictional force with and without air.

We investigated the effectiveness of this method for reducing frictional force and verified that a permeable air bag utilizing non-coated fabric produces an air layer between the air bag and human skin. Thus, it has become possible to greatly reduce the coefficient of friction through air lubrication.

We clarified that once a constant air layer has been formed, frictional force and coefficient of friction are not related to the material or structure of fabric, but are mainly related to the air mass that flows through the fabric.

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