The study on the relationship between the friction characteristic and the formability of the automotive steel sheet during the stamping process

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Abstract. This study aims to analyse the formability characteristics by friction characteristics of automotive steel sheets to improve sheet forming during the stamping process. During the stamping operation, the steel sheet is pushed into the tool surface, a complex phenomenon occurs, and many parameters interact. Therefore, automotive steel researchers want to optimize the friction of automotive steel sheets to improve the forming process, such as drawing ratio limit, dome height limit, cup drawing test, etc. In addition, in this study, the finite element method is used in combination with a numerical solution to present the friction behavior of high strength steel sheets in automobiles, taking into account the operating deformation mechanism during the formability test.

1. Introduction

Recently, many studies have been conducted to overcome concerns about the future environment and maximize energy efficiency. Various materials development and optimal method research are being conducted for this purpose, and in the automobile field, many efforts are being made to contribute to industrial development based on low carbon-green growth by achieving maximum energy efficiency through light weight of the vehicle body. Above all, many studies are being conducted on the development and application of high-strength steel for automobiles to reduce the weight of the vehicle and at the same time improve the strength, which has the advantages of light weight effect and passenger safety. As a result, interest in environmental regulations and passenger safety, which are discussed internationally, is increasing, and the application rate of high tensile strength steel is rapidly increasing.\textsuperscript{1-8)} Above all, the steel sheet applied to the car body for light weight should be designed and properly developed and applied in consideration of the characteristics required for each component. However, in the case of metal materials in general, strength and elongation have an inverse relationship, so we face the problem of overcoming the plasticity of high-strength steel for complex structural component parts of cars, and a lot of research is being done in various ways to solve this. Various high-strength steel sheets applied to the car body are manufactured through sheet metal forming processes and applied to actual parts. Since there are many process variables in the manufacturing process, whether to use them is determined by how to control them, and thus an optimization process is required. Generally, there are various process variables such as blank size, blank holding force, shape, sheet thickness and speed in the sheet metal forming process.\textsuperscript{9-17)}

In general, friction, wear, and lubrication should always be considered for all mechanical elements in contact relative motion, and many studies have been conducted to improve the characteristics at the interface through solid lubricants, surface coatings, and high performance lubricants. In this regard, it is possible to improve the formability of high-strength steel sheet because it is possible to induce high
formability by improving the mold settling characteristics of automotive steel sheet. Specific application techniques include Advanced Zinc Coating, Lubrication Sheet, and Surface Texturing. However, due to the low reproducibility of the experimental values, the friction coefficient of the material is generally used only for relative comparison, which makes it difficult to reflect the friction coefficient in the FEM. This characteristic is due to the fact that the coefficient of friction (COF) is not the inherent properties of the material, but the value of the system properties that are affected by the surrounding environment and test conditions. Therefore, in this study, in order to investigate the forming efficiency and deformation behaviour of automobile steel sheet through the change of friction characteristics, which have been recognized as uncontrolled factors, firstly, the reproducibility of friction coefficient value was verified by controlling the test conditions of friction coefficient measurement test. Second, we tried to evaluate the effect of the friction characteristics of the steel sheet on the formability by reflecting the COF as the main factor in the FEM.

2. Friction Test
In this study, reproducibility of friction coefficient test equipment was first evaluated to determine whether the friction factor values are reflected in the FEM (Finite Element Method). The friction coefficient test equipment used in this study was a single-sided sliding type pneumatic friction test equipment with a contact pressure of 20 MPa and 78.4 MPa, with a drawing distance of 0.1 m, a drawing speed of 0.2 m / min, and anti-rust oil applied after ethanol degreasing. The equipment schematic is shown in Figure 1, and the test conditions are shown in Table 1.

In this experiment, SGAFC590 steel sheets were measured three times at 10-day intervals to verify the reproducibility of friction coefficient measurements. The yield strength of SGAFC590 specimen is 323 MPa, tensile strength is 577 MPa, elongation is 28% and thickness is 0.7mm. The coefficient of friction value is expressed as the mean and standard deviation of the 30 measurements.

![Figure 1. Schematic of sliding type friction equipment.](image)

| Table 1. Test condition |
|------------------------|
| Test factors | Test condition |
| Contact pressure | 20MPa, 78.4MPa |
| Drawing speed | 0.2m/min |
| Travel distance | 100 mm |
| Working temperature | Room temperature |
| Degreasing | Ethanol |
| Lubrication | Rust prevention oil |
A reproducibility test result of friction test was shown in the Table 2.
In addition, in order to ensure the reproducibility of the test results, the vertical load was applied uniformly by adopting a method of loading from bottom to top. In order to minimize specimen tearing or slip, process factors such as correction of counter-edge curvature and checking of jamming load were checked in advance. As a result of the test, specimen slip did not occur until the contact pressure was 160MPa.

| Contact Pressure | 1st COF   | 1st SD   | 2nd COF   | 2nd SD   | 3rd COF   | 3rd SD   | Average COF | Average SD |
|------------------|-----------|----------|-----------|----------|-----------|----------|-------------|------------|
| 20MPa            | 0.1405    | 0.0012   | 0.1430    | 0.00077  | 0.1375    | 0.00071  | 0.1403      | 0.0024     |
| 78.4MPa          | 0.1432    | 0.0018   | 0.1436    | 0.00210  | 0.1374    | 0.00127  | 0.1414      | 0.0033     |

Under the conditions of contact pressure of 20MPa and 78.4MPa, the values of the friction coefficient were measured at 0.1403, 0.1414, and the standard deviation was 0.0024 and 0.0033, respectively.

3. FEM analysis
In order to evaluate the influence of factors affecting the formability of automotive steel sheets, the shape of the Dash Pot was selected, and the deformation behaviour was investigated using the Fractional Factorial Design method. Dash pot was used to evaluate the effect of the main factors affecting each deformation behaviour. In order to induce high formability, the variable corresponding to the processing efficiency was designed to have the maximum value.
Figure 2 shows the shape of the dash pot and the forming analysis conditions that are commonly used to examine this formability, and to analyse the effects of the main factors, the major factors are set in the range of -1 to 1. Fractional Factorial Design was used for friction, work hardening index, material strength factor, and R-value in each direction. As a result, the Fractional Factorial Design was conducted through the results of wrinkles, safety, and fracture. Marked results correspond to the area obtained from the FEM results. In Figure 3, the optimal conditions are set for the case where the wrinkles are less than 2%, 0% for the fracture and 98% for the rest of the range is safe, and the resulting satisfaction is obtained. In the graph showing safety results, the larger the slope, the greater the sensitivity of the value. In the case of friction, it can be seen that it has a much larger value than the slope of other factors.
Comparing comprehensively, the smaller the friction, the larger the work hardening index, the smaller the material strength factor, and the larger the R value in each direction, the more favourable the formability. It can be seen that the large sensitivity factor is the effect of friction.
Based on these results, we tried to check the impact of the center pillar, which is the main part of the automobile. Figure 4 shows the forming analysis conditions of the commonly used Single Action type of Center Pillar. At this time, only the coefficient of friction coefficient was change, and the degree of

![Figure 2. Forming condition of Dash pot](image)
Improvement in formability was analysed by marking the fracture and possible cushion stroke at the forming limit curve.

In the case of 980DP steel sheets, the initial fracture occurs gradually decreasing as COF decreases. On the other hand, in the case of 590DP, when the COF was 0.13 and 0.105, no breakage occurred and the forming was safely completed.

Figure 5 shows the point of the Cushion Stroke for each type of steel in which the initial fracture occurs. Even though the COF decreases for 980DP, the FEM result shows that the initial fracture is not
significantly reduced, whereas for 590DP, the initial fracture stroke changes significantly as the friction decreases.

Based on this, assuming that the standard deviation of the COF for fracture and crease is about 0.005, and the overall tendency follows the normal distribution, the difference in the degree of occurrence of crease and fracture according to the change of the COF can be confirmed. When the COF decreases from 0.18 to 0.13, the wrinkles showed a difference of about 1.72%, and the fracture occurred about 0.8%.

In addition, if the coefficient of friction decreases from 0.13 to 0.105, there will be a difference of about 0.7% in wrinkles and about 0.32% in fractures. Through this, it is considered that the change of the friction coefficient affects the formability of automobile steel sheet.

4. Conclusion
In this study, to maximize the formability of automotive steel sheets, we tried to improve the efficiency by controlling the friction characteristics that were considered as the uncontrolled factors. The effect of friction was investigated through the FEM and result analysis of the center pillar.

(1) By controlling the test environment of the friction test, the Coefficient Of Friction (COF) within the deviation 0.004 was obtained. Through this, it was confirmed that the COF the steel sheets can be reflected as a major factor in the FEM.

(2) A Fractional Factorial Design method was used using the Dash pot.

(3) The analysis of friction, work hardening index, material strength factor and R value in each direction showed that the sensitivity of friction coefficient had the greatest influence.

(4) The FEM was performed by changing the coefficient of friction from 0.18 to 0.105 for the center pillar, which is the main part of the vehicle body. For 590DP, the fracture occurred only when the COF was about 0.18.

(5) Assuming that the standard deviation of the friction coefficient for the occurrence of fracture and creases is approximately 0.005 and that the overall distribution of distributions follows the pattern of normal distribution, it can be found that there is a difference of up to 2.42% for creases and an increased probability of occurrence up to 1.12% for fractures.

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