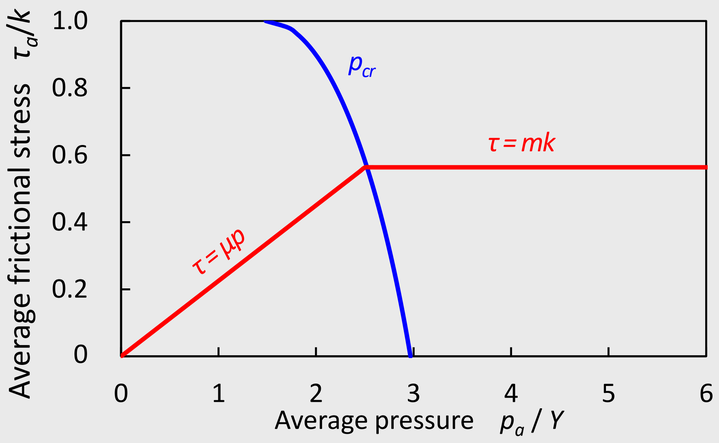
Proposed Friction Law



$$\tau = \mu p \ (p \le p_{cr})$$

$$\tau = mk \ (p > p_{cr}) \qquad m = \sqrt{3}\mu(-3.82\mu + 3.0)$$

$$\frac{p_{cr}}{Y} = \frac{2}{\sqrt{3}}\left(\frac{1+\sin 2\varphi}{2} + \frac{\pi}{4} + \varphi - \theta\right)$$

$$\varphi = \frac{1}{2}\cos^{-1} m$$

Figure 1: Proposed friction law.

(Wang, Z.G., Yoshikawa, Y., Suzuki, T., Osakada, K.: Determination of friction law in dry metal forming with DLC coated tool, Annals of the CIRP, 63(2014), pp. 277-280.)

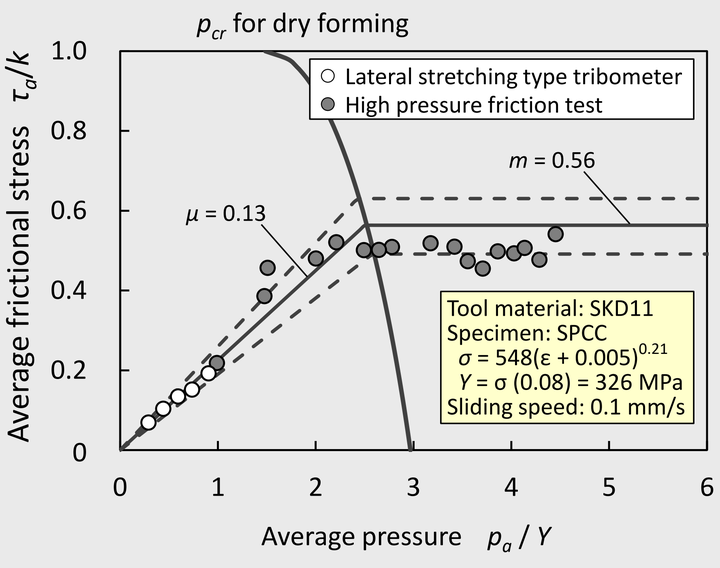


Figure 2: Relationship between average frictional stress and average pressure.

(Wang, Z.G., Komiyama, S., Yoshikawa, Y., Suzuki, T., Osakada, K.: Evaluation of lubricants without zinc phosphate precoat in multi-stage cold forging, Annals of the CIRP, 64(2015), pp. 285-288.)

Subroutine and Model

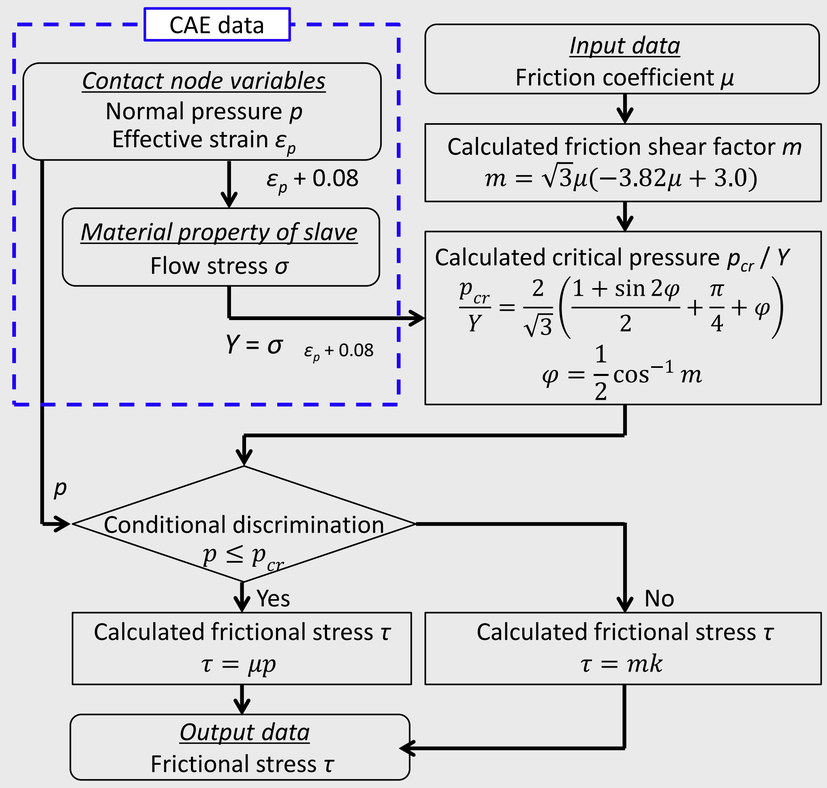
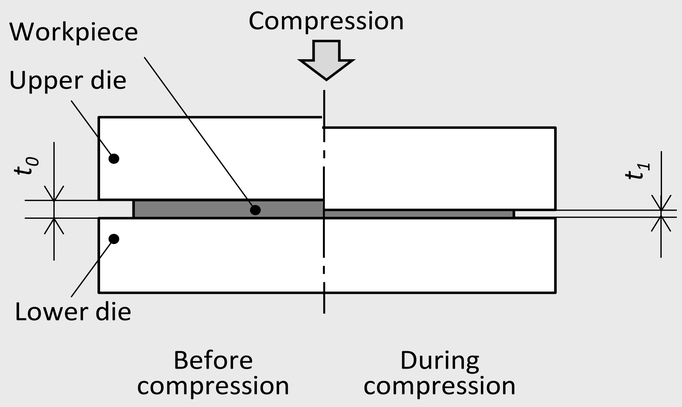


Figure 3: Flow chart of subroutine using proposed friction law.



Workpiece

Cold rolled steel shirt SPCC

$Y = 549\ (\varepsilon + 0.005)^{0.21}$

Pure cupper C1100

$Y = 503\ (\varepsilon + 0.002)^{0.39}$

Figure 4: Schematic illustration of compression test simulated by FEM.

Results

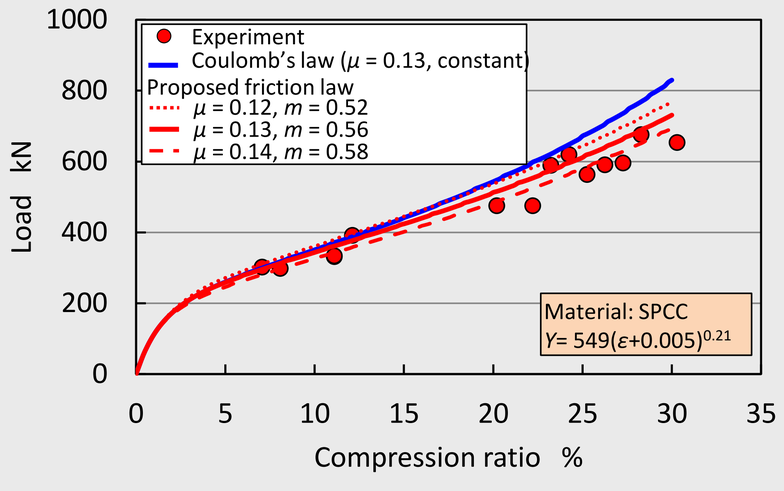


Figure 5: Compression load in disc compression test of SPCC.

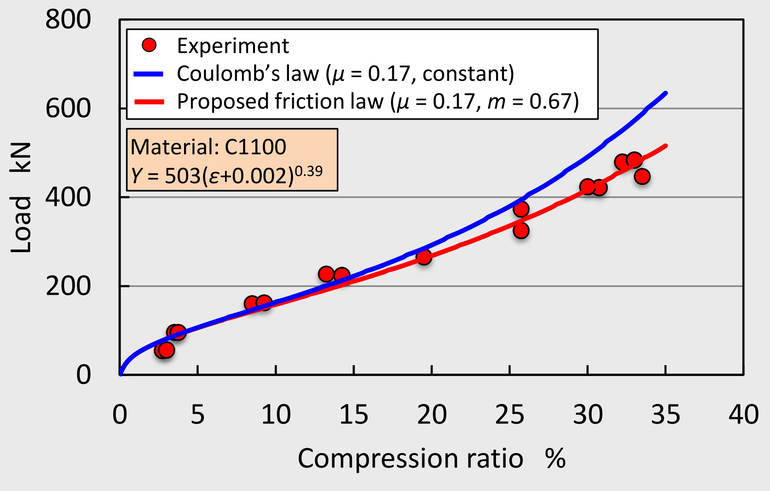


Figure 6: Compression load in disc compression test of C1100.

- **Proposed Friction Law**

Recently, new friction law for dry metal forming is proposed by authors. The feature of proposed friction law in dry metal forming is that Coulomb's friction law is applicable at lower pressure, and frictional stress is constant at higher than critical pressure p_{cr}. The critical pressure is formulated as shown in **Figure 1**.

The proposed friction law has been verified by experiment. **Figure 2** shows the relationship between average frictional stress and average pressure. In the region of lower than the critical pressure, Coulomb's friction law is satisfied. On the other hand, the region of higher than the critical pressure (p_{cr} = 2.50) is in the state of constant frictional stress.

The programed subroutine using proposed friction law for FEM analysis is verified by applying to the simulation and experiment of metal forming.

- **Subroutine and Model**

The FEM simulation is carried out using a commercial code DEFORM-2D ver.11. The flow chart of subroutine using proposed friction law is shown in **Figure 3**. The critical pressure p_{cr} is calculated by using the flow stress Y that the calculated effective plastic strain of the value added 0.08 to the previous step.

The simulated model is disc compression test as shown in **Figure 4**. The material of the workpiece is assumed cold rolled steel shirt SPCC and pure cupper C1100 (specified by JIS). The workpiece has disc shape with 20 mm of diameter and 1 mm of thickness.

In this study, Coulomb's friction law and the programed subroutine using the proposed friction law are applied to the simulation of disc compression. The simulated results are compared with experimental result.

- **Results**

Relationship between compression load and compression ratio of the SPCC and pure cupper C1100 are shown in **Figure 5** and **Figure 6**. It is certainly that the simulation result using the proposed friction law is near the experimental results. The programed subroutine using the proposed friction law can simulate accurately the experiment.

- **Conclusions**

1. The pressure of the proposed friction law in the disc compression test is lower than the pressure of Coulomb's friction law in the region of the center of workpiece.
2. The compression load of the proposed friction law is indicated near the experimental results.
3. The programed subroutine using the proposed friction law can simulate accurately the experiment.

Verification of Program Using New Friction Law for Cold Forging

Yasuharu Yoshikawa
Gifu University

Tatsuhiro Suzuki
Gifu University

Zhigang Wang
Gifu University