Development of combined loading test apparatus for checking the path-dependence of forming limit stress curve

Toshihiko Kuwabara
Professor
Division of Advanced Mechanical Systems Engineering, Institute of Engineering
Category: Advanced Manufacturing Technology
Keywords: plasticity, sheet metal, combined loading, forming limit stress, forming limit strain
URL: http://www.tuat.ac.jp/~kuwabara/

1. Summary of Research (Technology and Development)

We have developed a combined loading test apparatus as shown in Fig. 1, conducted the first and second punch-stretch-forming tests, and measured forming limit curves (FLCs) along linear and combined load paths. The FLC measurement along the linear load path uses a cylindrical punch with a diameter of 100 mm. In the combined loading test, the first process uses a 180 mm cylindrical punch to apply equibiaxial tensile prestrain to the sheet sample. Then the second process uses a small punch (15mm x 84mm with a tip radios of 7.5 mm) to put the center of the specimen in plane-strain state. With these processes, we have reproduced combined load paths without unloading.

![Combined loading test apparatus and schematic illustrations of combined loading test](image)

The measurement results of the forming limit strain are shown on the right in Fig. 2. Open circles (○) indicate the measurement values along a linear load path, and the squares (■ and □) along combined load paths. In the latter case, the cylindrical punch is raised 40 to 60 mm to apply equibiaxial strain in process 1 and plane-strain deformation is applied to the sheet and the forming limit strain is measured in process 2.
These are apparently smaller than the FLC measured for linear load paths, which demonstrates the strain path dependency of FLC\(^1,\,\,2\).

The forming limit stress curve (FLSC) measured for linear loading paths and the forming limit stresses for the combined loading paths are shown on the left in Fig. 2. The calculated values of the forming limit stress under the combined loading based on the isotropic hardening theory (■ and ■) generally agree with those for linear loading (+). Assuming that FLSC is independent of the strain path, this has demonstrated that it is effective in practice to estimate the rupture stress along combined loading paths by computation.

Fig. 2 Forming limit stress curve (left) and forming limit curve (right) for cold rolled steel sheet\(^3\)

\[\text{Forming limit stress curves} \quad \text{Yld2000-2d (M=6)}\]

2. Originality of Research (Technology and Development)

Using the combined loading test apparatus we developed, we measured the forming limit strain of a sheet metal along linear and combined load paths and confirmed the path-dependence of the forming limit curves (FLCs). Then we have calculated forming limit stress curves (FLSCs) by numerical analysis using an anisotropic yield function. As a result, it has been confirmed that the FLSCs are independent of the strain paths, which has demonstrated the effectiveness of FLSCs as a method for estimating the forming limit of sheet metal under combined loading\(^1,\,\,2\).

3. Future Prospects

We are planning to modify the die shape to reproduce various combined loading paths and apply this test method to high-tensile strength steel sheets.

4. Resources, Bibliography and References

