ABSTRACT


Kata-kunci : Polipropilen; simulasi komputer; uji pengrusakan; benchmark data.

1. INTRODUCTION

Recently, to cut development time, reduce prototyping cost and improve quality, CAE is being commonly used at the design stage. However, the accumulation of know-how for analysis, e.g. procedure to measure material properties of thermoplastic materials and treatment in numerical simulation, are not sufficient to evaluate impact performance of plastic parts by CAE.

Mechanical properties of solid thermoplastic materials consisting of millions of monomers differ from that of metals consisting of arranged atoms of metal. Furthermore, since semi-crystalline polymers such as Polypropylene consist of a crystalline phase and an amorphous phase, these mechanical properties have high non-linearity.

Although, some papers explain their detailed mechanism [1,2], further research on generating material data and numerical treatment in numerical simulation [3,5] is necessary to use CAE software properly.

This paper describes the detail of a benchmark test selected to develop these analysis know-how and a brief overview of case studies by crush analysis code.
2. MECHANICAL PROPERTIES OF THERMOPLASTIC MATERIALS

Generally, mechanical properties of thermoplastic materials are strongly dependent on strain rate, temperature and direction of load. Furthermore they are dependent on molding or process conditions to make plastic parts and humidity for some plastics.

Some factors affecting mechanical properties are shown in following paragraph.

2.1 Effect of Molding Condition

Injection molding process is often used to make plastic parts of ABS or Polypropylene. Since thermoplastic material is melted and injected in a mold under high pressure in this injection molding process, it is difficult to maintain the temperature or pressure history of material uniformly over the part. Mechanical properties often vary even in the same part. Figure 1 shows the distribution of Young's modulus measured from results of compression tests of a specimen, cut from dumb bell test piece (JIS K6810) made by ABS resin (UBE cycon, VW10), by universal tester.

This result shows that mechanical properties are distributed even in such a simple shape specimen, and this implies that some consideration of this distribution is necessary when generating mechanical properties for CAE analysis, e.g. averaging by typical mesh size.

![Figure 1. Result of compression test](image1.png)

![Figure 2. Appearance of test piece after tensile test](image2.png)
2.2 Effect of Strain Rate

Figure 2 shows a photograph of a test piece made of transparent ABS resin (Ube cycon, CTB3505) after tensile test by universal tester. Whitening by void or crazing, which is a peculiar phenomenon of thermoplastics, is observed in this photograph. The outward appearance of whitening varies strongly with a slight change of strain rate, i.e. stripe-like whitening under lower strain rate and uniform or mist-like whitening under higher strain rate. This can be related to the sharing mechanism of load in the specimen. So, it is easily understood that the effects of strain rate on mechanical properties of thermoplastics are significant.

2.3 Effect of Ambient Temperature

Figure 3 shows the result of tensile test varying ambient temperature. This plot shows that the yield stress is significantly dependent not only on strain rate but also on ambient temperature within the range of experience in service conditions and this dependency cannot be ignored.

Furthermore, temperature rises during test due to visco-elastic phenomenon and low conductivity of thermoplastics added further complexity. Figure 4 shows the temperature rise inside the specimen during compression test.
3. BENCHMARK PROBLEM FOR CRUSH ANALYSIS

3.1 Stress of Strain Curve of Material

Polypropylene (rubber toughened PP by grand polymer) which is widely used for automotive parts is selected for benchmark problem. Stress-strain relationships necessary for crush analysis are measured by injection molded JIS K71113 type 2 dumb bell specimen and compression/tension tester specially designed for thermoplastics and made by the author's laboratory.

Figure 5 shows the result of true stress-true strain relationship obtained from extension from gauge length of 25mm and load from load-washer during tensile test assuming volume conservation conditions. The lines of strain rate of 0 (static) and 133 (1/s) are extrapolated from experimental data by Malvern type constitutive function.

Figure 5. True stress-true strain curves

3.2 Test Piece for Benchmark Problem

Test piece for benchmark problem is cut from a plate with ribs injection molded by polypropylene, and its width, height and depth are 30, 32.3, 30 mm, respectively. This has an open box shape and its sidewalls are tapered; the thickness at the top end is 1.7mm and that at bottom end is 1.2 mm. Figure 6 illustrates the geometry of the test piece.

Figure 6. Test piece for benchmark test
3.3 Test Apparatus for Benchmark Test

The test drop weight type impact test apparatus designed to maintain repeatability shown in Figure 7 is used for benchmark test.

![Figure 7. Schematic illustration of crush test apparatus](image)

4. RESULTS OF EXPERIMENT

4.1 Result of Crush Tests

As an example of a benchmark test, the load vs. displacement relationship when a weight of 26.26 kg is dropped from 10 cm height is shown in Figure 8. A photograph of the test piece after a crush test is shown in Figure 9.

![Figure 8. Load-displacement curve](image)
5. RESULT

Several case studies on this benchmark problem by using PAM-CRASH', RADIOSS' and LS-DYNA' are carried out. Through these case studies, effect of each numerical parameters on accuracy of analysis result are investigated and methods to improve accuracy are developed by comparing these analysis results and experiments. The following paragraph will describe some examples of case studies by PAM-CRASH [6].

5.1 Case Study 1: Effect of Mesh Size

First of all, the effect of mesh size which determines computing cost of analysis is investigated. Figure 10 shows fine mesh used in these case studies. Coarse mesh is generated by doubling the mesh size from this fine mesh. The analysis result of this case study and effect of mesh size are shown in Figure 11. Strain rate dependency was considered by specifying all curves shown in Figure 5. Although both analysis results underestimate the first peak of load by about 20% at displacement of 3mm, the displacement of the first peak and displacement and load of the 2nd peak at displacement of 9mm show good agreement with experimental results. Overall behavior is re-produced by analysis, except for the displacement of over 12 mm.

Figure 9. Photograph of test piece after test
5.2 Case Study 2: Effect of Strain Rate Dependency

Consideration of strain dependency of mechanical properties is also effective in computing cost as mesh size. Comparison of analysis results with and without considering strain rate dependency of stress-strain relationship is shown in Figure 12. Consideration of strain rate on stress-strain relationship is done by using all curves shown in Figure 5. Consideration is also done by using single curve (select strain rate of 0.002 or 3.42 as typical strain rate) from Figure 5. Coarse mesh size shown in the previous paragraph is selected for this case study.
Whereas the result of typical strain rate $0.002 \text{ (1/s)}$ under-predicts the experiment, the result of typical strain rate $3.42 \text{ (1/s)}$ and result considering strain rate dependency shows good agreement with the experiment. Although there is no procedure to determine the typical strain rate, this case study shows that by estimating appropriate strain rate, computing cost can be reduced.

5.3 Case Study 3: Effect of Imperfection

The specimen used in this benchmark problem has imperfections; within its four open ends, two ends are 0.2mm higher than others. In previous case studies, these imperfections are considered at finite element modeling. In this case study, analysis results without considering this imperfection are investigated. This may occur with use of CAE at design stage. Figure 13 shows the result of the case study. There are significant over estimates of load over a wide range of displacements in the analysis results without considering initial imperfections. This shows that it is important to consider such a small initial imperfection, especially in the contact region in crush analysis. Other case studies about mesh geometry, modeling of contact or friction, etc. are carried out in the same manner as the above paragraph.
6. CONCLUSION

Factors affecting mechanical properties for crush analysis of thermoplastics are investigated. Through several case studies by ‘PAM-CRASH’ upon benchmark problem by a box-shape specimen cut from plate with ribs made from Polypropylene, the following are confirmed: Molding conditions to make the test specimen, strain rate and ambient temperature during test, significantly affect mechanical properties within the range of service conditions. So, it is important to consider these dependencies in crush analysis to design plastic parts. Effects of mesh size are not significant within the range of size of mesh selected in this report. Further case studies are necessary to investigate the effect of mesh size. There are possibilities to reduce computational time by selecting appropriate typical strain rates. Further case studies are necessary to establish the procedure to estimate typical strain rate. Consideration of small initial imperfection at the contact area significantly affects the analysis result. Detailed representation of this geometry at finite element modeling is necessary in crush analysis. Further case studies to investigate other numerical solution parameters, e.g. time step at explicit analysis, shape of element, modeling of contact and friction are necessary to establish understanding of crush analysis for thermoplastic parts. Further case studies, investigation and enhancement of benchmark tests are being carried out among members of the working group. Through these case studies, benchmark data, which can contribute to develop techniques or know how for crush analysis of thermoplastic part will be prepared. Techniques or know how developed through these case studies will be distributed and shared.

REFERENCES