AFDEX
Adviser for metal Forming process Design EXpert
Newsletter
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MFRC
Metal Forming Research Corporation
www.afdex.com, mfrc@afdex.com
Tel: +82-55-755-7529, Fax: +82-55-761-7529

Contents

1. AFDEX_V24R01 released

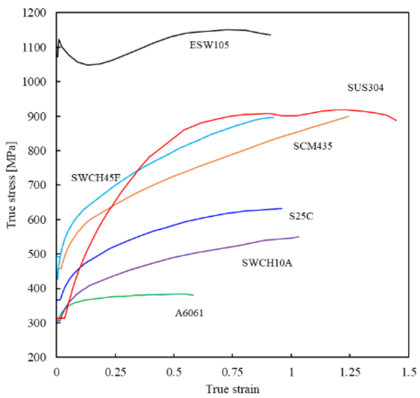
The V24R01 version is scheduled to be released in October 2024. New features of the solver and pre-processor and improvements to existing features can be found in the newsletter for the second and third quarters of 2024 and Sections 2 and 3 of this Newsletter.

2. New features of AFDEX_V24R01

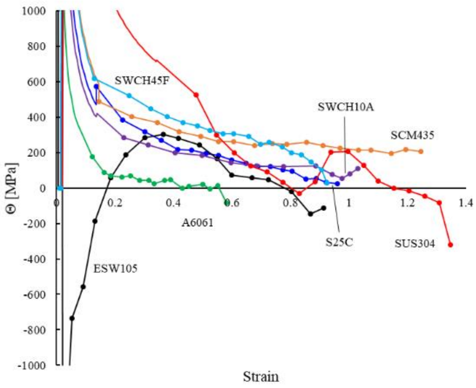
2.1 Tensile test and flow curve with its strain hardening capability

The properties of materials immediately before forging or metal forming, such as flow behavior, vary greatly depending on the history the material has experienced. Since the flow behavior is a factor that determines the metal forming process, the importance of a tensile test that easily provides detailed information about the flow behavior cannot be overemphasized. Considering the reality that we often encounter cases where the flow behavior extracted from tensile tests is incorrect even in academic papers, we must emphasize this point again.

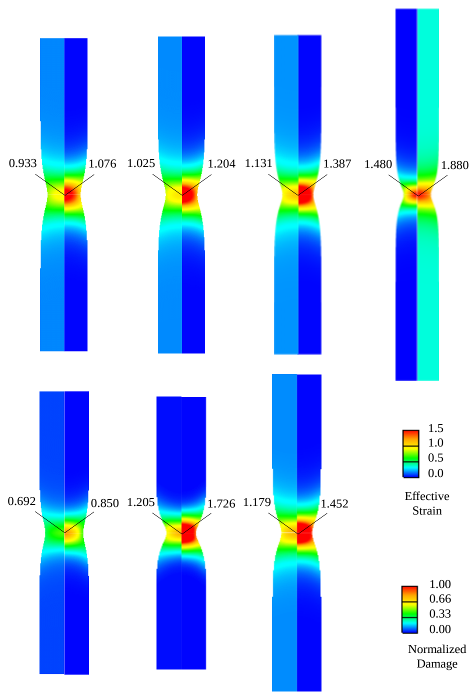
The existing AFDEX /MAT has provided a method of obtaining flow curves from tensile tests based on the rigid-plastic finite element method. Recently, a flow curve improvement technique using the elastoplastic finite element method has been developed. Figure 2.1 shows the flow behavior (Figure 2.1(a)) and strain hardening capability (Figure 2.1(b)) of various materials for automatic multi-stage cold forging (cold former forging). Figure 2.1(c) compares the results of tensile test analysis based on the same standard (gage length/diameter = 5) using flow curves obtained from the tensile test results of tensile specimens with different gauge length/diameter ratios.



(a) Flow curves obtained with tensile specimens of different specifications



(b) Strain hardening capability



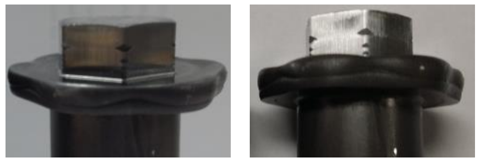
(c) Analysis results of tensile test using same size (L/D=5) tensile specimen

Figure 2.1 Identification of flow behavior from tensile test

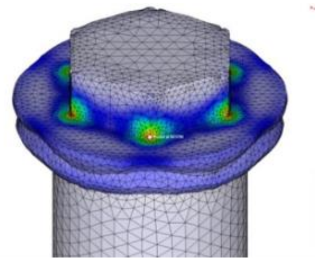
2.2 Accuracy of damage calculation

Analysis of bulk metal forming processes including forging inevitably requires re-meshing. Re-meshing improves the mesh system along with boundary conditions, but fundamentally introduces changes in state variables, including strain and damage. In general, the deformation of materials tends to occur in a diffusive manner. The law of mass conservation, strain hardening, and strain rate hardening contribute to this phenomenon. However, the situation regarding damage is different. Ductile fracture occurs partially, and the strain softening caused by damage develops in a direction that strengthens these harmful characteristics. Therefore, careful attention is required when assigning the mesh density during the re-meshing process. Damage acquired without such preparation or countermeasures taken into consideration may only mean a tendency.

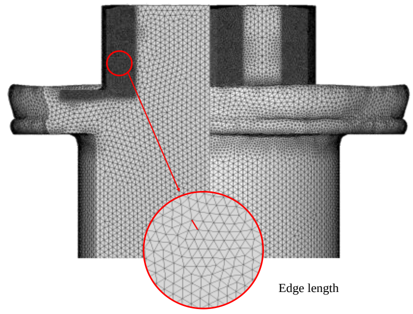
According to recent research works, when the edge length of finite elements around the crack is about 1/10 of the length of the target crack, damage that is resistant to re-meshing can be obtained. Figures 2.2(a) and (b) were presented by an AFDEX user (Seongjin FOMA) at the 2014 User Conference (MFCAE 2014). The results at that time were qualitatively significant. However, the location of crack occurrence could not be accurately predicted due to the smoothing caused by re-meshing. Figure 2.2(c) satisfies the mesh density requirements mentioned above, and the predicted results in Figure 2.2(d) are in line with the experimental results.



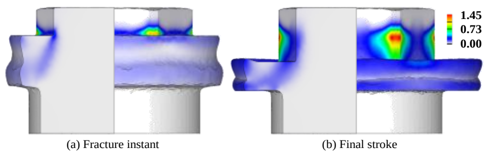
(a) Experiments



(b) FE predictions presented in the MFCAE 2014



(c) Optimized mesh system for crack prediction



(d) Result of meeting ductile fracture mesh density requirements

Figure 2.2 Prediction of damage and ductile fracture in bolt heading process

The tensile test not only provides a flow curve, but also yields information about critical damage at fracture. Therefore, the correlation between finite element refinement and damage to examine the mesh density requirements considering the ductile fracture is shown in Figure 2.3. This figure shows that the critical damage is 1.15, assuming that the finite element refinement requirements are met. Some researchers may try to devise and use practicality-oriented methods that treat critical damage differently depending on finite element refinement. However, as shown in Figure 2.2, it should be emphasized that utilizing AFDEX's intelligent re-meshing function allows for the use of an appropriate mesh system to acquire detailed ductile fracture information in most cases.

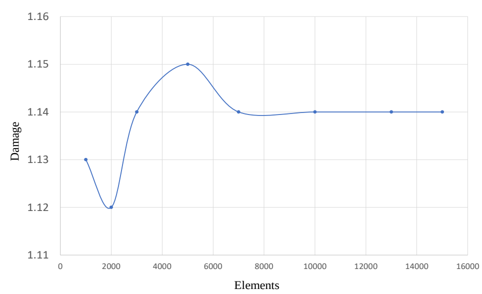


Figure 2.3 Relationship between finite element edge length and maximum damage at the point of fracture in tensile test

2.3 Direct input of die mesh system

The geometric information of the die generally consists of surface information. This information is discretized into a mesh system within the pre-processor or program for structural analysis and heat transfer analysis of the die. AFDEX utilized intelligent technology to promote a high level of user-friendliness and internalized the mesh system creation and reconstruction functions into the program. This is AFDEX's unique feature that enhances various functions and performance. Basically, AFDEX uses this function to create a mesh system for the die. Using this function, it is possible to control the mesh density to a sufficient level when creating the mesh system of the die. This is possible thanks to AFDEX's powerful intelligent re-meshing capabilities.

However, as there are no strict rules, there may be cases where the user must directly enter the die mesh system. For this case, when mesh system information is entered instead of die surface information, a function was added so that die surface information is automatically generated and the mesh system information can still be used for structural analysis and heat transfer analysis of the dies. However, it's important to emphasize that, like the material, the finite mesh system of the die automatically generated by the internal function of AFDEX can flexibly control the mesh density.

Figure 2.4 shows a simple application example to explain the concept. This feature is scheduled to become an official service starting from V24R02.

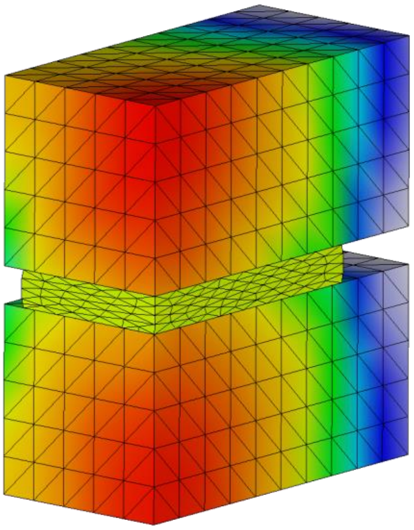
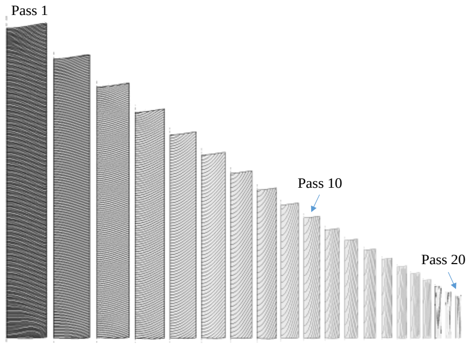


Figure 2.4 Example of use of the input die mesh system

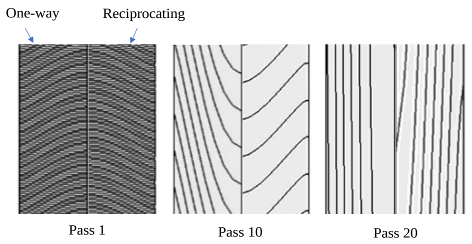
2.4 Automatic simulation of drawing process

The drawing process is basically multi-stage. However, automatic simulation is not easy. This iss due to the grip. Existing methods provided boundary conditions or placed a non-separable die at the bottom of the material. Complete automation was impossible in this way. In the new method, the grip part is formed through extrusion, which does not apply strain or stress to the material until the grip is created, and then automatic simulation is performed by deleting the extrusion condition and imposing a speed condition on the grip. Fully automatic simulation is possible regardless of the number of stages.

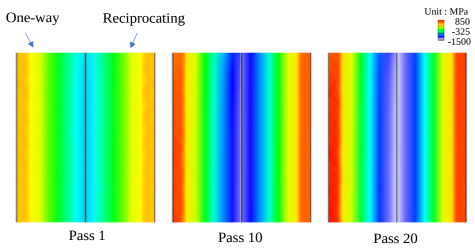
Re-meshing is very important in the analysis of the drawing process. Re-meshing is essential due to unnecessary increases in calculation time resulting from an increase in length and unexpected deformation occurring in the grip section. Points to consider in re-meshing of the drawing process are the simplicity of the material shape and mesh density. An issue that must be taken into account in the analysis of the drawing process is that residual stress is concentrated in the skin. The distribution of residual stress changes dramatically compared to that of strain near the skin. A way to take advantage of these characteristics is to use structural mesh systems in the 2-dimensional case, and also to use a directional skin dense mesh system in the 3-dimensional case. Figure 2.5 shows an application example of the 20-stage bar drawing process. The area reduction rate of each stage is the same at 10%. Figure 2.5(a) is a 1:1 scale representation of the final shape of each stage, and Figure 2.5(b) shows the flow lines immediately after the end of the 1st, 10th, and 20th stages enlarged to the same size. In Figure 2.5(b), the left side is the FE predicted metal flow lines of a one-way drawing process, and the right side is those of a two-way alternating drawing process. The left and right sides of Figure 2.5(c) show the axial residual stress components at the ends of the one-way drawing process and the two-way drawing process, respectively. The similarity of the two results means that the residual stress from the previous stage does not have a significant effect on material's plastic deformation of the drawing process at the current stage.



(a) Result after finishing drawing



(b) Metal flow lines when the diameter is equally enlarged



(c) Axial residual stress

Figure 2.5 Analysis results of drawing process

2.5 Simultaneous temperature and friction compensation of the flow curve at elevated temperature

Hot cylindrical compression tests are widely performed for obtaining the flow behavior of materials. When trying to obtain an accurate flow curve at elevated temperature, temperature and friction problems arise. Actual hot compression tests are performed under non-isothermal conditions. Although it is commonly called isothermal conditions, isothermal conditions cannot be maintained in practice due to the plastic deformation heat generated during the compression test. The temperature rise that occurs during a compression test of a specimen varies from material to material, but Ti alloys are an extreme case. This is because, although they have high strength, their heat capacity is low and heat conduction occurs slowly. If it is assumed that the displacement-compression load occurred in an isothermal and frictionless state, the true stress-true strain curve, that is, the ideal flow curve, can be obtained through manual calculation. The ideal flow curve of magnesium and titanium alloys shows a significant difference from the actual flow curve. Therefore, friction and temperature compensation must be performed. In other words, errors arising from the assumption of frictionless and isothermal conditions must be corrected.

Figure 2.6 is about magnesium alloy AZ80A. The solid line is the ideal flow curve, and the one-dotted line is the formula for this. When temperature compensation is performed in this mathematical model, the final flow curve is a dotted line. When the compression test was analyzed using this flow curve, its FE predictions with sufficient accuracy were obtained. Magnesium alloys have a very large difference in flow stress depending on temperature, so even small temperature changes have a significant effect on flow stress. The effect of friction is relatively small. Therefore, there is no need to provide compensation for friction. Flow stress increases at the contact surface due to friction, but in the case of frictionless contact, the contact area remains large, so they cancel each other out in terms of compressive load. However, the case of aluminum is different. The magnitude of the influence of temperature and friction is similar. In general, when considering the effect of temperature, flow stress increases, and conversely, when considering the effect of friction, flow stress decreases.

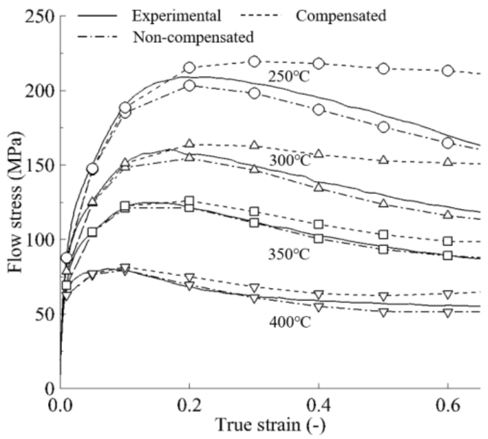
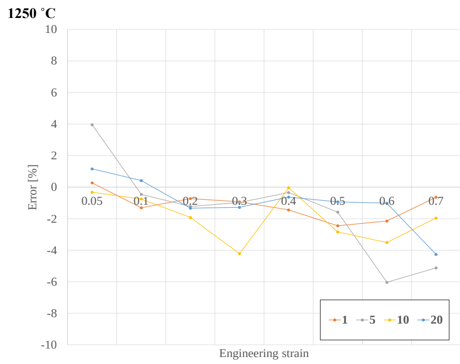
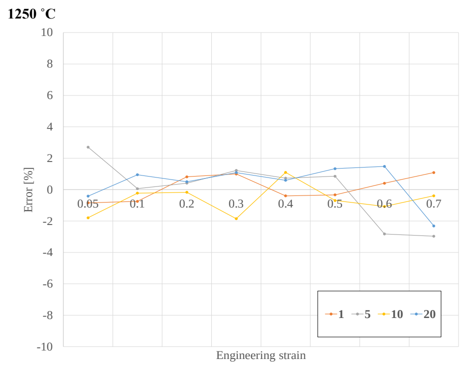


Figure 2.6 Flow curve of AZ80A at strain speed 1 (1/s)

As mentioned above, because aluminum alloys do not have a relatively large temperature compensation effect (because heat conduction occurs quickly), friction compensation also becomes important. Since the effects of the two factors on flow stress are not absolute, the effects of both friction and temperature must be compensated for. Friction compensation is generally more complex than temperature compensation. In reality, since the two influences interact, simultaneous compensation technology for both is necessary. Thus, a simultaneous temperature and friction compensation technique using AFDEX has been established. Figure 2.7 shows the error for the flow curve obtained using the AFDEX /MAT. As shown in Figure 2.7(a), the error is controlled to a low level through the minimization process in the acquisition stage of the flow curve. When using the latest temperature friction simultaneous compensation technique, the average error (from 2.4% to 1.8%) and maximum error (from 6% to 3%) are significantly reduced, as shown in Figure 2.7(b).



(a) Before improvement



(b) After improvement

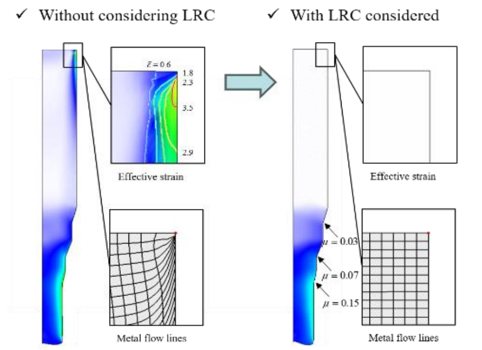
Figure 2.7 Temperature and friction simultaneous compensation results

2.6 Lubrication regime change in aluminum alloy forward cold extrusion with a stepped die

Recently, a developer group studied lubrication regime change (S. W. Lee et al., Tribol. Int. 2020, 141, 05855; N. A. Hamid et al., J. Manuf. Proc. 2024, 114, 178 -195; Y. Heo et al., Tribol Int. 2024, 197, 109755). In general, most applied researchers use the condition of a constant friction coefficient or constant shear factor. Wilson (W.R.D. Wilson, Friction and lubrication in bulk metal-forming processes. J. Applied. Metalwork. 1978, 1, 7-19.), who studied lubrication engineering linked to metal forming, criticized this reality 45 years ago. He argued that the constant shear friction law is applicable only in the thick film lubrication regime, but that this condition can only be maintained in the initial stage of forging and should not be used, and that the Coulomb friction law with a constant friction coefficient condition should also be avoided. It is even emphasized that the constant shear friction law is for theoretical scholars. He finds the cause of the uncritical acceptance of these two friction conditions in what engineers superficially learned about lubrication or friction when they were young.

According to research conducted by the developer group, friction has a greater influence in materials with low strain hardening capability, such as aluminum. In addition, before the surface strain related to the surface state of the material at the contact surface reaches a certain value, if the contact interface is well-lubricated, the friction coefficient is very small, but as it exceeds the critical strain, the friction coefficient rapidly increases, that is, a lubrication regime change occurs. It has been observed in numerous hot and cold aluminum forging applications.

Even in forward cold extrusion with a stepped die, which is widely performed, lubrication regime changes occur. If the lubrication condition is at a normal level, the surface of the extrusion product at the exit in the extrusion process shown in Figure 2.8 may be significantly damaged by the lubricant. However, direct contact between the material inside the container and the die may not occur. Considering the state of the material at the outlet, if the friction coefficient is set to 0.1 (Figure 2.8(a)) and the process analysis is performed (σ=50.3(1+20ε)^0.26 MPa), the pressure inside the container is increased by friction. As it increases, plastic deformation occurs on the surface, leading to the conclusion that extrusion is impossible. However, considering the lubrication regime change (Figure 2.8(b)), although the friction coefficient increases to 0.15 at the exit, the material inside the container does not yield. This example helps to visually understand the impact of friction variability, that is, lubrication regime change. Considering that the flow curve and friction conditions have a great influence on the FE predictions of metal forming processes, it is worth paying attention to the fact that the friction coefficient is highly dependent on the condition of the contact surface, i.e., lubricant status.



(a) Constant friction (b) Variant friction

Figure 2.8 Forward cold extrusion with a stepped die and lubrication regime change

3. Improvements of AFDEX_V24R01

3.1 Activation of network license

Until the previous version, AFDEX licenses were provided in a node-locked manner. Depending on the user's request for a network license, the network license type is changed to a floating method starting from V24R01. This floating type license also applies to users who use existing dongle keys.

3.2 Addition of analysis results view type for the entire process

Until the previous version, it was possible to view shading, mesh, outline, etc. individually for the material or die selected in the analysis results. Viewing methods such as shading, mesh, and outline, etc. for entire materials or dies are provided starting from V24R01 in the entire process, including the multi-stage process. This function can be confirmed by the icon in the View tab in Figure 3.1.

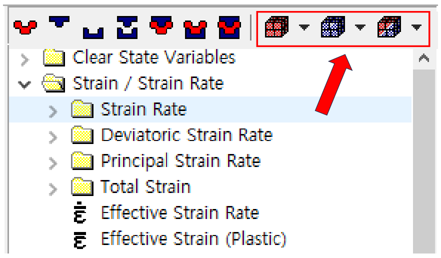


Figure 3.1 Add display type icon

3.3 Addition of dual Coulomb friction condition input UI

In V24R01, a UI is provided to input double Coulomb friction conditions. You can check the new friction condition input data in Figure 3.2.

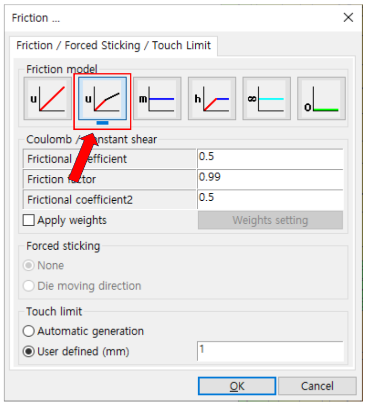


Figure 3.2 Double Coulomb friction condition input UI

4. Notice

4.1 Online education in 2024

Education of the theory and usage through the YouTube channel has recently been significantly reorganized. You can check out the theory of engineering plasticity and finite element method and how to use AFDEX on the AFDEX's official YouTube channel. In addition, education on statics, solid mechanics, and mathematics is provided for non-majors.

AFDEX's official YouTube address is as follows. (https://www.youtube.com/c/AFDEX)