AFDEX Newsletter Q3 / 2020

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1. Release of AFDEX_V20R01

AFDEX_V20R01 was released on 5th of June 2020. Major features of the new version were introduced in the previous newsletter. The release was delayed by two months compared to the release of new versions in earlier years. It is not only because many difficult and sophisticated functions were implemented or improved but also because the input and output structures were completely innovated for generality and extensibility. From standpoint of input/output, the new version is a completely new software even though usage is not changed much. The change of program structure is aimed to reinforce the functions of process optimal design, or high-level, specific applications requested by global users, particularly in elastothermoviscoplastic FE analysis, multi-body simulation, plate forging, springback analysis, etc.

As a consequence, more specialized FE analyses of user-oriented applications as well as more professional FE analyses for improved accuracy will become feasible. The new version will also assist the developers to respond more quickly to help the users with creative ideas or applications.

2. Improved functions of AFDEX_V20

2.1 Development of main plate using the die motion control function for plate forging

There have been continued improvements in terms of the plate forging through cooperation with German and Japanese users. In the newly released version, various analyses of the plate forging process are available due to the integration of the plate forging analysis functions. The features of the plate forging analysis can be summarized in several main categories: Various kinds of relative motion between dies, force exerting die (blank holding die or tool), accurate calculation of die strokes, springback, layered FE mesh system, piercing or trimming between stages. Until now, the functions of relative motion between dies and force exerting die, etc. have been fully tested. Figure 2.1 shows the predictions of the third stage in multi-stage plate forging. As shown in Figure 2.1, the forming load is applied continuously on die 1, while the primary die, die 2 drops 2.2mm. Then, die 1 and die 2 move together when the input value reaches the limit value. (K. K. Park et al., KSTP Spring 2020, 2020.06.25.).

From Figure 2.2 that compares the analysis and experimental result, it turns out that the simulation result matches the concept design.

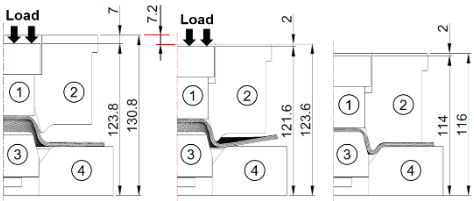


Figure 2.1 Plate forging process design

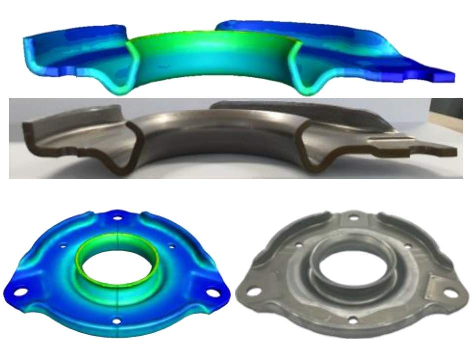


Figure 2.2 Comparison between experiments and predictions

In the previous newsletter, the same process was introduced with emphasis on improvement of functions for plate forging before its try-out. On the contrary, it was adopted again to emphasize the benefit of CAE technology because it was successfully developed without any failure.

2.2 Acquisition of flow stress information

The most important factor affecting the overall simulation results is flow stress. The second most important factor is the law of friction with its constants. These two factors fall under the purview of users. Application level of forging simulators is dependent on the governing capability of these two major factors.

AFDEX_MAT has a unique function for characterizing the flow stress of any incompressible material from tensile test of cylindrical specimen. AFDEX_MAT can calculate the flow stress at a large strain in room temperature. (For SCM435, computable up to around 1.5). In particular, considering the varying flow stress with pre-works including heat-treatment drawing, this simple and useful function is immensely helpful for advanced engineering activities. It should be emphasized that steady endeavor and improvement for better accuracy are particularly important in this context.

The related research was made 12 years ago, and its academic achievement was published in 2008 (Mechanics of Materials, V. 40, pp.586-593). Recently, the research related to this topic is becoming more and more active together with DIC technique. However, AFDEX_MAT is still powerful in terms of its accuracy and simplicity. We hope all users to become proficient at applying AFDEX_MAT to find much better material conditions which is different on a case-by-case basis. They can be supported by various materials including academic papers, simple tutorial manuals, internet educational materials, etc. Finally, it should be emphasized once more that the same material especially in cold forging may have different flow behavior depending on the pre-work. Thus, too much dependence on the flow stress information supplied by developers of metal forming simulators should be avoided.

Recently we started to support the users with a simple way of identifying flow stresses from the tensile test of sheet materials to fulfill the request from the users who are interested in bulk metal forming of sheet or plate materials. The details about this procedure can be advised by referring '2D Part2 Ex08' of tutorial manual.

2.2.1 Improved Hollomon's model

In the original version of AFDEX_MAT, the strength coefficient K was calculated as the function of effective strain including elastic strain. This feature was based on the concept that there is elastic deformation at the very beginning of total deformation in rigid-plastic analysis.

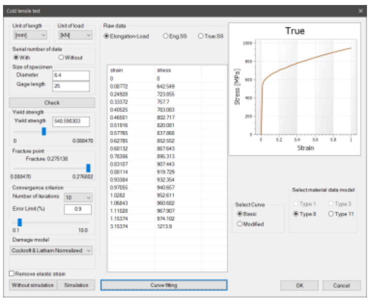


Figure 2.3 Improved Hollomon's model

Now, AFDEX_MAT provides enhanced modification control in elastoplastic analysis for converting K to $K(\varepsilon_p)$ where $K(\varepsilon_p)$ is a function of effective plastic strain. This can be done by clicking 'Remove elastic strain' box in the window shown in Figure 2.3. Figure 2.4 depicts the flow stress diagram only with respect to the plastic deformation obtained without considering the elastic deformation. For the elastoplastic analysis, the material properties such as Young's modulus, Poisson's ratio and coefficient of thermal expansion are used for the mechanics computation in the elastic region instead of the flow curve.

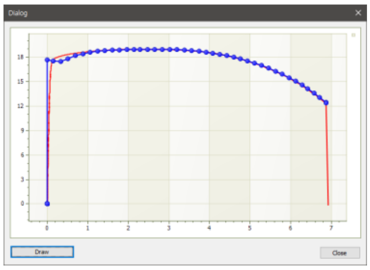


Figure 2.4 Comparison of experimental flow stress(red) and fitted flow stress(blue)

The previous version of AFDEX_MAT could apply the curve fitting for K of Hollomon's model ($\sigma = K\varepsilon^n$), which was aimed only for a round bar. In the new version, this function was improved to provide material characterization with regards to the sheet material, which needs inputs of engineering stress-strain data, cross-sectional area, gauge length, and yield point. Figure 2.5 shows the application.

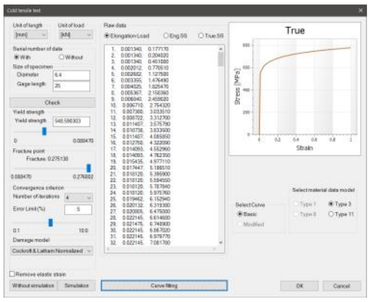


Figure 2.5 Improved Hollomon's model

2.2.2 Improved Swift model for elastoplastic analysis

Most sheet metal forming processes undergo bending and stretching during forming. Although the simulation can be done completely, the small value of the predicted strain was found to be within the range of 0.15 to 0.25. Recently, owing to the growth in demand for the crash analysis, for example, FE analysis up to fracture is strongly needed. In addition, the necking and/or the facture at unimportant region during the forming, which may be removed after forming, can be allowable for special cases. In this case, it is important to acquire the flow stress with respect to the higher strain beyond necking point.

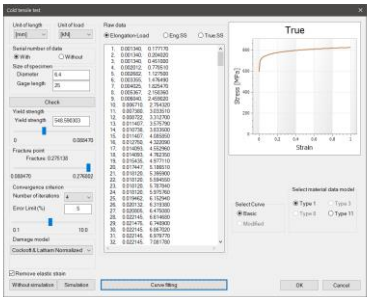


Figure 2.6 Swift model

The new feature which helps users to determine the material constants of Swift model ($\sigma = K(\varepsilon_0 + \varepsilon)^n$) using only the plastic strains is added. The first step to obtain the flow stress based on the elastoplastic finite element analysis is to enter input data as shown in Figure 2.6. Next, one can obtain the material constants by checking 'Remove elastic strain' box.

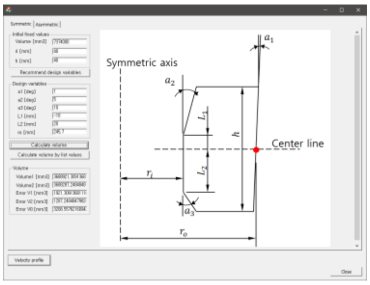
2.3 Ring-rolling process design

2.3.1 Preform design

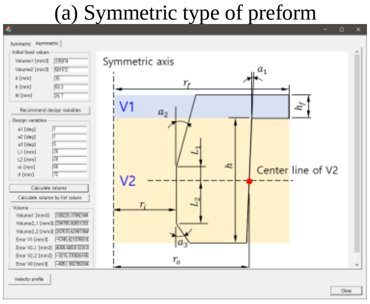
It is not complicated to design the preform of the ring-rolled product. However, it will be inconvenient in terms of calculating its volume. The preform which is ring-rolled has a chamfered edge because the forged product is used for the preform directly. This causes difference between the volume of upper part and that of the lower part which are separated by the center line. It is said to be the best preform design when the volumes of the upper and lower parts are the same. To handle this problem, ring-rolling process designers had calculated two volumes separately to match each other several times with 3D CAD.

Currently, the two types of preform designs are available as shown in Figure 2.7: symmetric type and flange type.

In the preform design program, the volume of two separate parts can be calculated by inputting the volume of the ring-rolled product and design variables. Here, if the error between the two volumes is close to zero, it can reduce the number of trial and error attempts. Plans are in place to provide the users with a minimization feature using optimal design at a later stage.



(a) Symmetric type of preform



(b) Flange type of preform (Asymmetric)

Figure 2.7 Ring-rolled preform design

2.3.2 Main roll motion design

One of the most significant factors in ring-rolling process design is to set the motion of the main roll. For beginners, it is not easy to design this process. Improper design of ring rolling process can lead to various kinds of failure, including polygonal shape defect, poor roundness, etc. From the latest version, a function for supporting users to conduct engineering design of main roll motion is supplied, as can be shown in Figure 2.8.

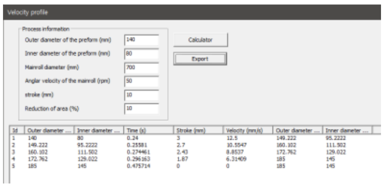


Figure 2.8 Ring-rolling main roll motion design

2.4 AFDEX downloader

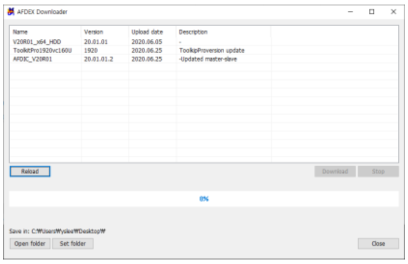


Figure 2.9 AFDEX downloader

AFDEX_V20R01 provides AFDEX downloader for quicker response. One can check for software updates and download newly available patches through AFDEX downloader. Automatic updating and patching system will also be released soon.

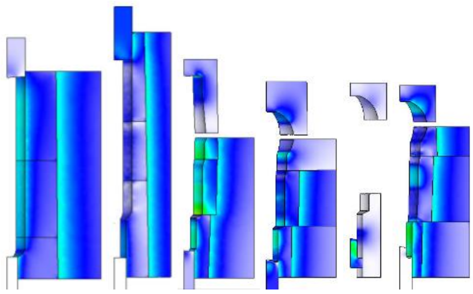
3. Examples of professional applications

In this section, three major applications among the presentations made in KSTP Spring Meeting 2020 are introduced. For more details, please refer to the link below. (http://www.afdex.com)

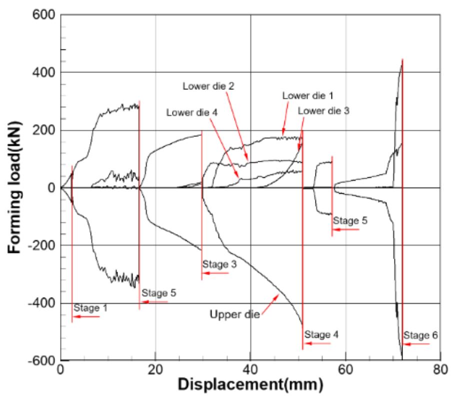
3.1 Complete Analysis of Automatic Six-Stage Cold Forging for SUS 304 Ball-Stud

Effects of temperature softening and die elastic deformation on forming load in automatic multi-stage cold forging of a SUS304 ball-stud were quantitatively analyzed using complete analysis technology.

SUS 304 is a high strength material which is one of the hardest materials to be used for cold forging. Owing to its high strength, however, intense growth in the temperature during the forging can be observed. It causes decrease in the flow stress, and this phenomenon can be remarkably found in SUS 304 especially. It turns out that the forging will be impossible from the predictions obtained without considering the effect of the temperature. On the other hand, the predictions will be opposite when the effect of the temperature is considered.



(a) Effective stresses of die inserts and shrink rings



(b) Forming load – stroke curve

Figure 3.1 Complete analysis of SUS 304 ball-stud

An automatic six-stage cold forging process of SUS304 ball-stud in Figure 3.1 can be such an example. The material can be heated up to 400℃ in high-speed production and consecutive forming stages, which are characteristics of automatic multi-stage forming processes. This kind of temperature rise takes place particularly around the most severe deformation region where the flow stress of the material decreases considerably. In fact, flow stress reduces by about 42% when the material is heated to 400℃ from the room temperature. In this case, non-isothermal analysis with elastic die deformation would rather be considered.

In this simulation, FE analysis of a cold forging process was conducted, considering die elastic deformation. Thus, fully coupled analysis between elastoplastic material and elastic dies as well as between flow analysis problem and heat transfer analysis problem was made simultaneously. Like the increase in temperature, the consideration of viscous heating results in decrease in forming load or die stresses which may eventually affect the final decision of the forgeability and process design.

3.2 Dynamic strain aging (DSA) and its related flow stress in cold forging

It has been known that the flow stresses of S35C and S45C increase as temperature increases in a certain range of state variables including temperature, strain and strain rate. This phenomenon, called as dynamic strain aging(DSA), observed by Potevin and Le Chatelier (thus sometimes called PLC effect), are opposite to the common well-known phenomena of thermal softening of metals, which have been studied actively from the 1970s. Recently, some academic attempts have been made to model the flow stress behavior to be applied in the engineering works of metal forming processes, because these phenomena have a deep metallurgical and mechanical influence of some issues of processes and products including surface crack. In particular, as explained in Section 3.1, its necessity has gradually risen to respond to the request of precision simulation of cold forging of high-strength materials. These phenomena occur in most metallic materials including steels, aluminum, titanium, etc. It was, however, reported that SUS304 stays out of this effect even though distinct evidences of the DSA were observed.

In this section, an example of distinct DSA phenomenon in the range of actual cold forging of S25C by automatic multi-stage cold forging machine is introduced, which was presented in KSTP Spring Meeting 2020. Figure 3.2 shows the flow stress curves formulated as a general power law model and fitted using AFDEX MAT with the experimental flow stress curves. The comparison shows an excellent agreement with each other. This fitting or modelling procedure is essential to reflect the material flow behaviors on the predictions. The smoothing procedure is positively beneficial to alleviate the oscillatory experimental flow behaviors caused from jerk or serrated flow. There have been many research works to model these flow stresses under the DSA effect, but they only have a qualitative meaning. Because of their complexities and material uniqueness, a general description is almost impossible at this moment.

AFDEX_MAT supplied a general material model, i.e., power-law model of which material parameters are formulated by piecewise bi-linear functions of sample temperatures and strains. As already discussed, AFDEX_MAT gives us very accurately fitted flow stresses over the entire range of state variables, as seen in Figure 3.2.

It is interesting to note that the flow stresses show a normal distribution up to around 200C, that is, flow stresses decrease as temperature increases and that its tendency becomes reversed after critical temperatures, depending on strain and strain rate. These phenomena are related to DSA and can be accurately described by a general power-law model using AFDEX_MAT.

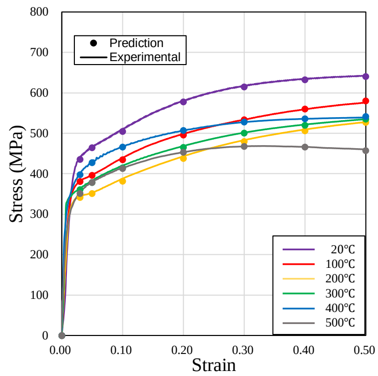
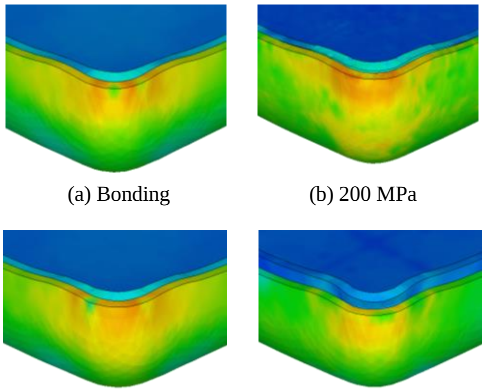


Figure 3.2 Experimental and fitted flow stresses

3.3 Three-dimensional elastoplastic FE simulation of delamination phenomena in composite sheet metal forming processes

Applications of composite metallic materials have steadily attracted the researchers because of their utility in special processes. These materials can take advantage of the strong points of all the materials employed. However, they have their weakness of fracture along the interface, called delamination phenomenon, during deformation. Thus, FE simulation technology for the composite metallic materials is of great significance to compensate for their decisive weakness. The FEA technology for them is characterized by their unique mechanical and thermal forming conditions, contact treatment schemes, fracture criteria for checking delamination, and multi-body treatment schemes. In this newsletter, a special example of multi-body simulation with emphasis on fracture along the originally stuck interface is introduced. The material is composed of three layers with different mechanical properties. Along the sliding interface, law of Coulomb friction was applied while Tsai-Wu fracture model was applied along the stuck interface. Four different interface conditions were assumed, that is, complete bonding condition in Figure 3.3(a), bonding strength of 200 MPa in Figure 3.3 (b), bonding strength of 300 MPa in Figure 3.3(c) and unbonded condition in Figure 3.3(d).

The predictions shown in Figure 3.3 depict that the third case is almost the same with the complete bonding case, the first case, while the second case shows partial delamination. The different look between the first and third cases is owing to different contact conditions causing different mesh systems. The fourth case showed that the sliding occurs when the material undergoes plastic deformation.



(a) Bonding (b) 200 MPa

(c) 300 MPa (d) Unbonded

Figure 3.3 FE analyses of sheet metal forming processes of composite materials

4. Notice of cancellation of MFCAE 2020

MFCAE, an international conference of AFDEX users or CAE technology researchers, has been held on an average, three times every four years since 1996. In response to the continued evolution of COVID-19 pandemic, MFCAE stands canceled this year. AFDEX members wish all users to keep best health condition for actively taking part in MFCAE next year.

However, we will actively support AFDEX users online and will also continue to engage with anyone interested in metal forming and its CAE technologies. We will inform them of all our activities and share our knowledge, experience related to AFDEX and its theoretical background through online platforms or webinars.

Once more, we hope you all to stay safe and maintain good health.