AFDEX Newsletter
Q1 / 2020
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Contents

1. AFDEX_V19 and AFDEX_V20

1.1 New Features and Improvements

AFDEX_V19R01 with new and updated features was released on April 2019. Since then, the numerical characteristics had been improved in AFDEX_V19R02 released on August 2019.

1.2 Main Features of AFDEX_V19

In this section, some selected examples which had been presented or published in the related conferences or journals in 2019 are briefly introduced.

1.2.1 Complete Analysis of Crankshaft Hot Forging Process with Much Reduced Computation

Complete analysis, that is, fully coupled analysis between die-material deformation as well as flow and heat transfer problems of a hot forging process of a crankshaft was conducted using rigid-thermoviscoplastic finite element analysis function of the latest version with die deformation coupled with plastic deformation of material. Note that the computational time was reduced drastically by a factor of 5, compared with the previous version. Fig. 1.1 shows some predictions of the complete analysis.

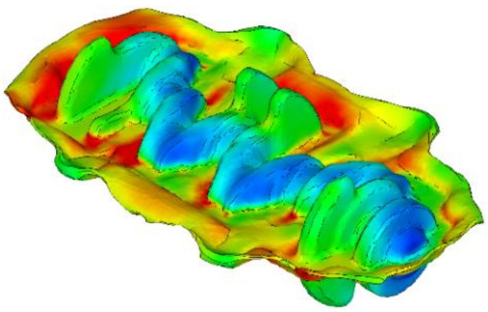


Fig. 1.1 Selected predictions of the complete analysis

1.2.2 Multi-body Forming Process

Multi-body plastic deformation problems are hot issues in metal forming simulation. AFDEX started to be applied for several multi-body forming processes since 2018. AFDEX V19 has experienced more complicated and actual processes than before, as can be seen in Fig. 1.2 and Fig. 1.3. Fig. 1.2 shows an example of multi-body simulation for assembling hub bearing unit by rotary forging process.

Two taper-roller bearing inner races were treated as separate bodies which have no constraints.

Fig.1.3 shows elastoplastic FE predictions of a forming process for assembling three parts. The comparison between 2D results in Fig. 1.3(a) and 3D ones in Fig. 1.3(b) shows good similarity of effective stress.

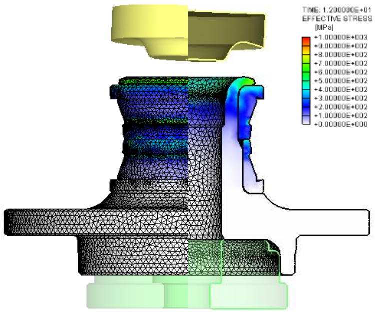
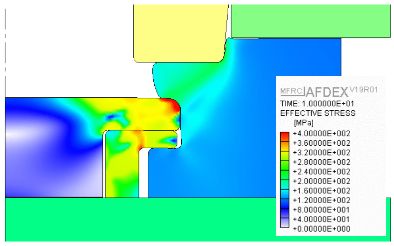
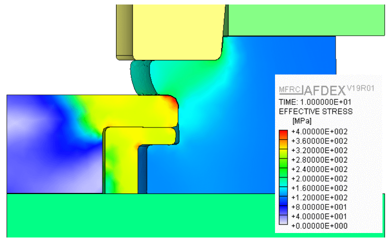


Fig. 1.2 Residual stress of a hub bearing assembly



(a) 2D



(b) 3D

Fig. 1.3 Joining process of three workpieces

1.2.3 Complete Analysis of Springback

Springback is getting more and more important for precision metal forming to minimize machining cost, to save global environments and to improve product quality. Springback is caused from thermal load as well as mechanical load. A complete analysis, that is, fully coupled analysis between die-material deformation including flow-temperature analysis is conducted.

Unloading process and ejection process were all analyzed, and the predictions are shown in Figure 1.4. The predicted distances

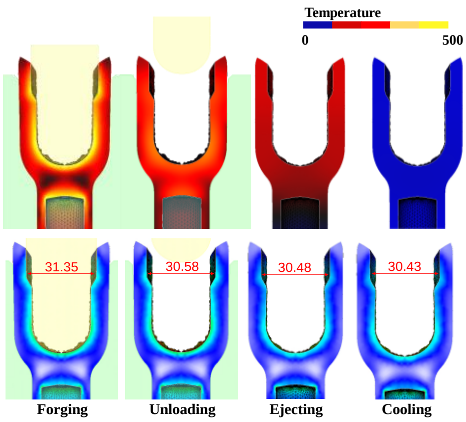


Fig. 1.4 Springback analysis of a yoke forging process

1.2.4 Coining Process

Coining process is one of extreme cases in terms of number of elements. Die surface is drawn by an artist and it is thus very delicate. Therefore, the material surface should be treated with very fine and intelligent surface mesh system which needs very high number of elements. Fig. 1.5 is one of artificial coining processes that needs more than one million elements for a precise description of side wall and letters.

Fig. 1.5 Coining process simulation

1.2.5 Dieless Forming Process

Dieless forming is one of the special forming processes in terms of die or tool motion. Most previous research works about this process employed shell or plate elements. However, the tool-material contact area is so small that pure stretching assumption cannot be applied to the dieless forming process. Therefore, solid element approach has some strong points because local deformation of thickness can take place by lateral contact force. Fig. 1.6 shows an example of dieless forming process.

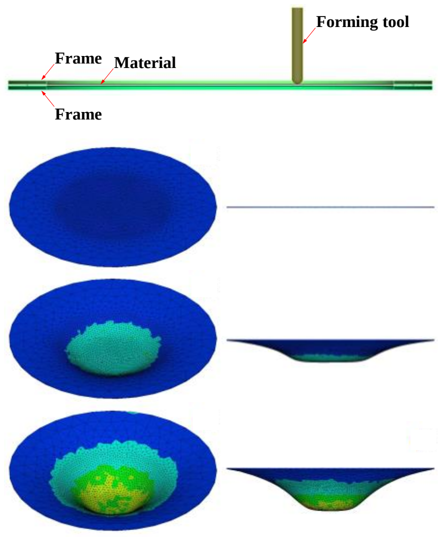


Fig. 1.6 Dieless forming process simulation

1.2.6 Open-Die Forging of Larger Slab

An open-die forging process of larger slab was simulated to conduct process design optimization to increase product quality as well as yield rate. Fig. 1.7 shows a typical example, which consists of about 300 blows. The simulation was conducted in a fully automatic way, i.e., user-intervention is made only when material adjustment is needed, for example, rotating and initializing it.

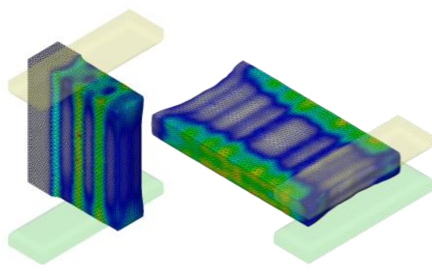


Fig. 1.7 Open-die forging of a larger slab

1.2.7 Sheet Metal Forming Simulation

Sheet metal forming process was simulated by solid element approach. One of hottest issues in the field of sheet metal forming simulation is the FE analysis using solid elements which can solve the inherent defects of traditional sheet metal forming simulation technology based on shell or plate elements, for example, local thinning phenomena.

Fig. 1.8 shows an example of applying solid-element based FE approach to a sheet metal forming process of oil pan.

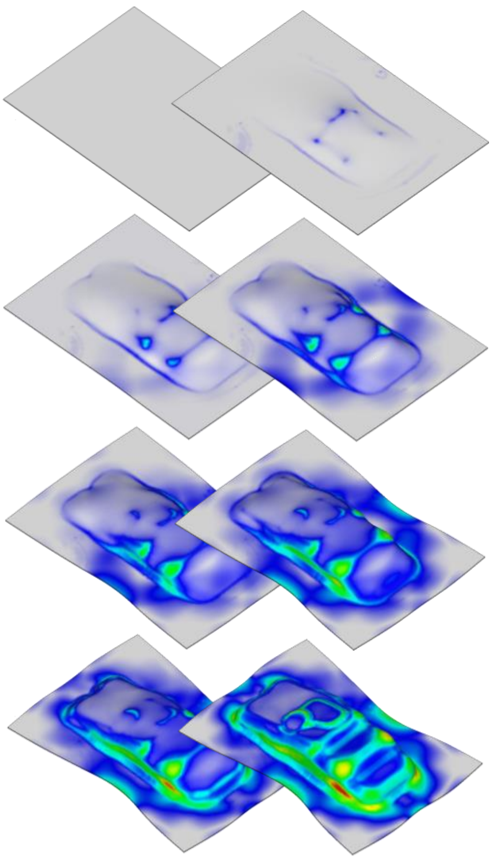


Fig. 1.8 FE simulation of oil pan forming process

1.2.8 Plastic Deformation of Stent

Elastoplastic finite element analysis of stretching a bundle of wires was conducted which belongs to a kind of extreme multi-body plastic deformation problem in terms of generality in contact treatment. Fig. 1.9 shows predictions of plastic deformation of a bundle of fine wires for medical use.

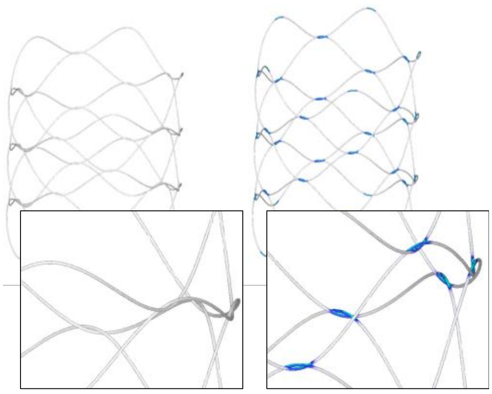


Fig. 1.9 Stretching a bundle of wires

1.2.9 Structural analysis of assembled die

Accurate contact treatment in conducting structural analysis of complicated assembled dies considering shrink fit and planes of symmetry is of great importance in terms of solution reliability.

Numerical jumps of stress components can be frequently met especially at die corners because of geometric and numerical complexities. In the latest release, V19R02 provides some advanced functions of predicting stresses of assembled dies. Figs. 1.10 and 1.11 compare the new predictions with the previous predictions, indicating that the predictions exhibit much more stable solutions.

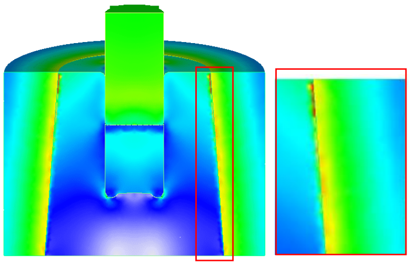


Fig. 1.10 V19R01

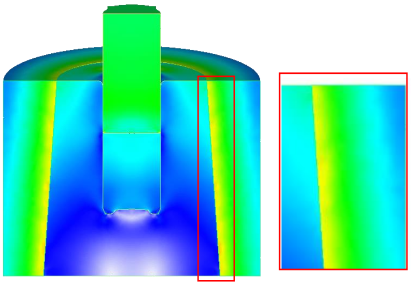
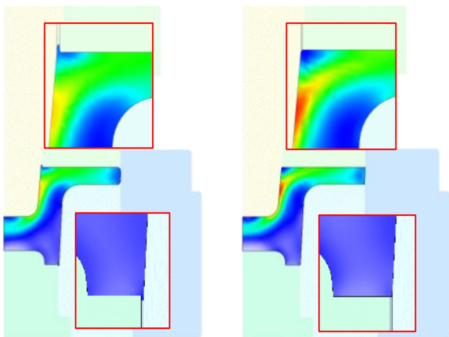


Fig. 1.11 V19R02

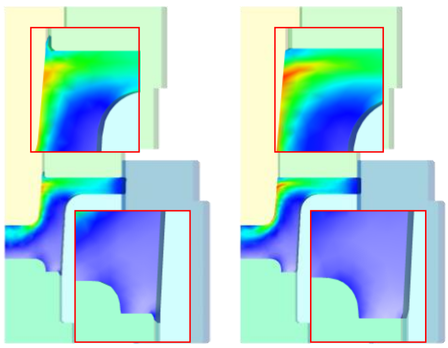
1.2.10 Sophisticated Treatment of Gap Flow of Material between Die Parts

Assembled dies for predicting their associated metal forming processes are more realistic. However, some numerical schemes are inevitably necessary to deal with gap flow between die parts, and users need to consider the methods of dealing with it.

Therefore, a scheme of preventing the material from being flown into a small gap between the die parts is inevitable. i.e., practical and general schemes related to the gap flow prevention is necessary. The previous version has supplied a function which shows good results for some specific problems. For the latest version, V19R02, we improved its generality considering the various cases. Figs. 1.12 and 1.13 illustrate the capability of gap flow prevention for 2D and 3D examples, respectively, which are purposely artificial process designs.



(a) Allowance of gap flow (b) Prevention of gap flow
Fig. 1.12 Two-dimensional example



(a) Allowance of gap flow (b) Prevention of gap flow
Fig. 1.13 Three-dimensional example

1.2.11 Coarsening STL die information

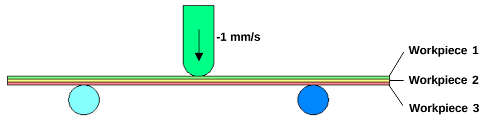
Fine die surface information constructed by a STL format with so many triangular patches may not contribute to enhancing the solution accuracy when the finite element mesh system of material is not compatible with the die information in terms of mesh size. For the fine die surface model to be meaningful, the FE mesh system of the material should be much finer.

When the die STL input is so fine, it would rather be coarsened in a direct way. Thus, a new coarsening function will be delivered from V19R02, to make it compact in terms of computational efficiency. Fig. 1.14 compares input surface and modified surface. Note that the former is described by 420,000 tetrahedrons while the latter by 30,000 tetrahedrons, revealing that the number of triangular patches were drastically reduced with negligible loss of surface characteristics.

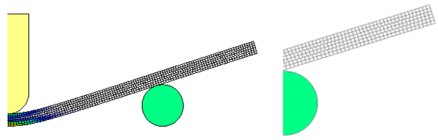
(a) 420,000 tetrahedrons (b) 30,000 tetrahedrons
Fig. 1.14 Example of the new coarsening function

1.2.12 No-Slip and Non-Separation Condition for Multi-Body Simulation Function

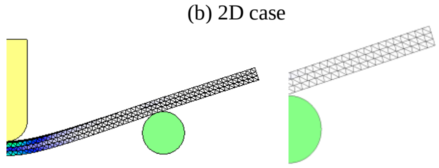
Figure 1.15 below shows an analysis results of 2D & 3D V-bending process of composite sheet under the condition of no-slip and non-separation along the interface between different materials. During the simulation, remeshing can be conducted either automatically or manually. This function has a distinct advantage over the analysis of metal forming with composite materials and can be developed in a way that analyzes for the delamination in the interface of composite sheets



(a) Process concept



(b) 2D case



(c) 3D case

Fig. 1.15 Analysis result of V-bending process of composite sheet

1.2.13 Direct Coupling of Material and Die

In general, indirect coupling approach is applied to simulate metal forming processes. That is, each object is solved independently and correlation, action and reaction between materials or bodies are dealt sequentially that causes some inaccuracy, which is inevitable. A direct coupling approach is beneficial to solve this problem, which solves the entire process involving material and a part of die parts at the same time without any iterations between separate problems. In the direct approach, the interface of different materials is treated by the penalty method and frictional condition can be considered.

Figure 1.16 shows a typical example of the direct coupling approach for simulating a stage of a ball-stud cold forging process. This stage is mechanically complicated because of the side die with spring and needs accurate simulation because the potential premature die fracture during backward extrusion for the hexagonal hollow end. An artificial binder die exerting force depending on its displacement is employed just below the die part. Note that the binder die exerts the exact force calculated from its displacement velocity, preload, etc.

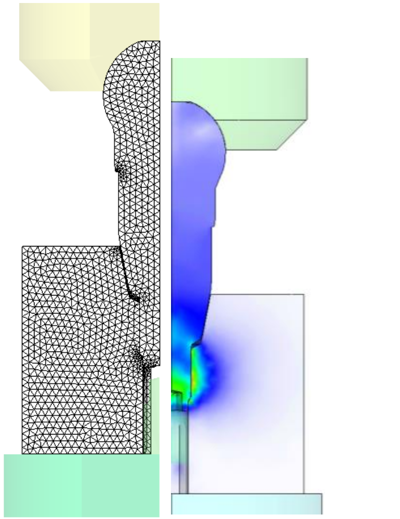


Fig. 1.16 Directly coupled analysis between material and die. (L) FE model, (R) Effective stress at the final stroke)

1.2.14 Analysis Considering Cooling Channel

Sometimes, cooling of dies needs to be carried out using the cooling channel. Most metal forming processes commonly do not require the flow analysis for a coolant inside a cooling channel, which makes problems much complicated and the effectiveness is very low. Considering this reason with the factor of coolant flowing in high speed, a method is provided in practical way to take account of heat transfer between a workpiece and a coolant which is maintained at an assumed constant temperature. Figure 1.17 illustrates the analysis of cooling die using cooling channel.

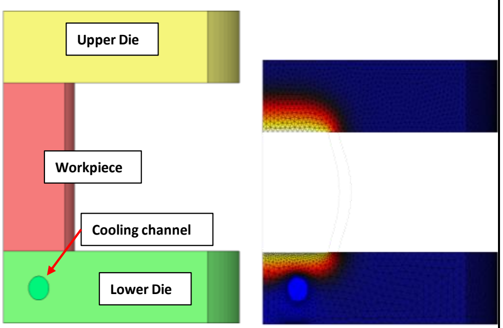
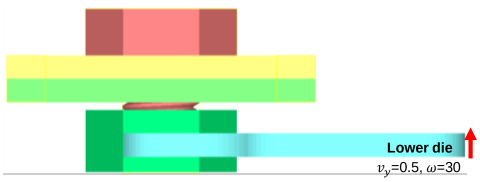


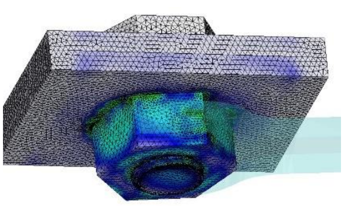
Fig. 1.17 Heat transfer analysis for a die considering a cooling channel

1.2.15 Analysis of Tightening Process Using Bolted Joints

The tightening process of bolted joints is one of the representative examples of multi-body processes. The cases of relatively small slip during assembling or forming multi-bodies has been already introduced in previous newsletters and related academic papers. The tightening process of two plates with bolted joints shown in Figure 1.18 is representative of a drastic multibody process which is characterized by its long slip along the interface, i.e, an extreme case of multi-body forming problems.



(a) Process definition

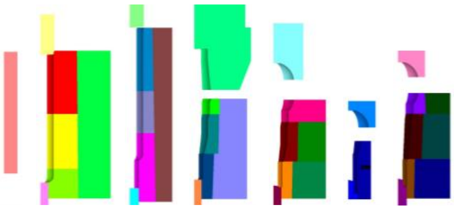


(b) Effective stress at the final stroke

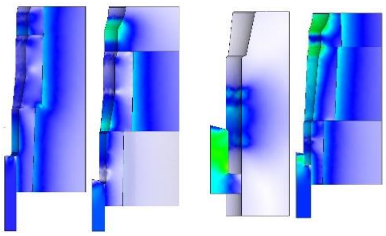
Fig. 1.18 Analysis of tightening process of bolted joints

1.2.16 Analysis of Assembled Die Forging Process

Recently, the analysis functions of simulating assembled-die forging processes are improved, which are inherently exposed to some numerical problems due to complicated die geometries. It is highly likely that there will be some numerical jumps caused by shrink fit, singular points or edges, i.e., geometric discontinuities between die parts and planes of symmetry. Lately, various methods have been developed to remove these problems. Figure 1.19 shows effective stress contours of die parts in a typical automatic multi-stage cold forging process.



(a) Process design



(b) Effective stress

Fig. 1.19 Predictions of an automatic multi-stage cold forging process of a ball-stud

1.2.17 New Material Model for Flow Stress at Elevated Temperature

We had been working on a research developing a flow stress model of high-temperature material considering recrystallization, and the outcome was published recently in J. Mater Res Technol.(2019, Vol. 8, p. 2710). The flow stress model has an advantage of being not only the most accurate way of expressing a complicated flow stress obtained experimentally, but also a means of increasing generality. It is applicable in expressing flow stresses for the various high-temperature situations. Even though there are too many material constants used for the model, they can be calculated easily by an optimization function. The relevant models in this case are Model 27 and Model 28. As shown in the Fig. 1.20 that compares Model 27 and 27 with others, those two Models are superior to the others in accuracy.

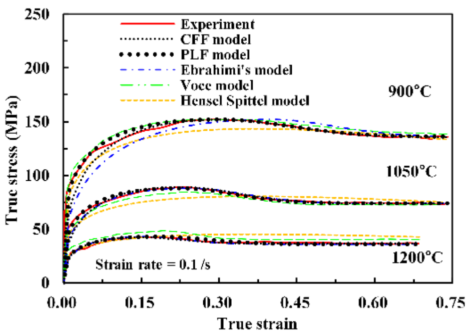


Fig. 1.20 Verification of CFF and PLF model of AFDEX

1.2.18 New Material Model for Flow Stress at Room and Intermediate Temperatures

A considerable decrease in flow stress is caused by increase in temperature due to viscous heating during an automatic multi-stage cold forging process. It implies that temperature has a great influence on the plastic deformation and forming load of a material. Therefore, a change in flow stress which depends on a change in temperature must be considered essentially for the forging of high-strength materials. As temperature of a material increases, the velocity dependence of the flow stress inevitably increases. In order to reflect the deformation characteristics of a material at room and intermediate temperatures, a closed-form function model is proposed, which is added on the program as 'Model 29.'

Note that the flow stress model is developed based on experimental study on SUS304 and that it can be applied to the other materials because it is general and flexible. Figure 1.21 shows the flexibility of the proposed model. It is noteworthy that a necking occurs on the same elongation over all the flow stress curves.

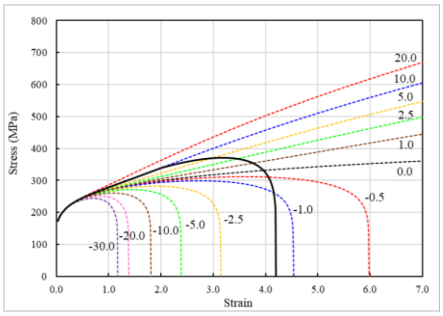


Fig. 1.21 Flexibility of the proposed model

1.3 The Latest Features of AFDEX_V20

1.3.1 New Function of Simulating Normal Open Die Forging Processes

The open die forging analysis in AFDEX had been focused on a complicated process such as stepped and/or hollow bar. In the previous version, manual intervention was needed in the case of changing stages. In the newest version, new feature is added, which allows to automate analysis of whole processes where motions of dies are comparatively simple as in the case of normal cogging process for long and uniform bars. The main input conditions needed for the process analysis are the range of movement allowed by manipulators located on the both sides of the material, plastic deformation limit, period, target reduction, moving position of dies, and parameters for tuning the analysis results based on the experimental results or experiences for each pass. A pass is composed of a series of the same blow by the same pairs of dies. Figure 1.22 shows the typical application example.

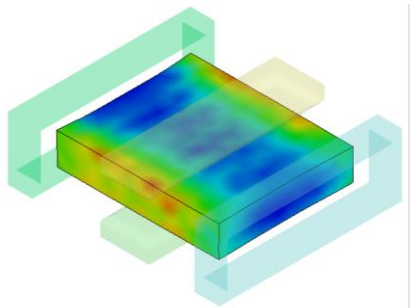


Fig. 1.22 Completely automatic simulation of a standard open-die forging process

1.3.2 Improvement in Multi-stage Rolling Process Analysis

It takes a lot of time for modeling the multi-stage rolling process. Also, it needs extra procedures and times to measure the section force and the cross-section area between two rollers. Now, although the design variables such as a roll gap or an interval from a roller to the adjacent roller are changed, it can be easily fixed to run a simulation. Also, the new feature is added so that users can easily check the values of tensile force and compressive force between the rollers or a cross-sectional area of the center of the roller. Fig. 1.23 describes the analysis result of the multi-stage rolling process and the cross-section of each stage.

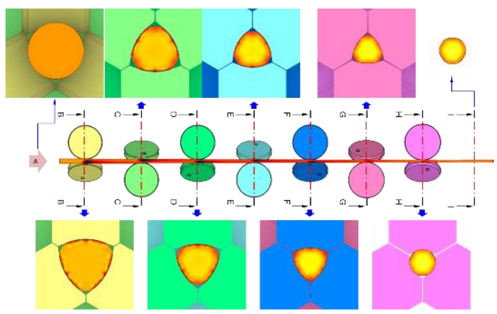


Fig. 1.23 Analysis results of multi-stage rolling process

1.3.3 Binder Working along the x-Direction

In shearing of a rod, users now can apply a binder from the side. Fig. 1.24 describes the analysis result with using the binder working in x-direction during the shearing process.

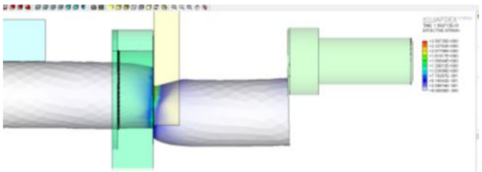


Fig. 1.24 Binder working along the x-direction

1.3.4 Improved Feature of Slave Motion

Fig. 1.25 illustrates the simulation result of the plate forging process where the slave motion is applied. There was a problem that a die penetrates the other one, when dies are activated while they have contacted each other. In the newest version, this problem is solved by improving the function of binder.

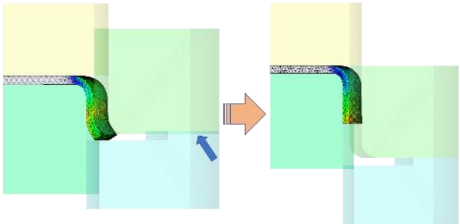


Fig. 1.25 Slave motion caused by the contact of dies

1.3.5 2D Multi-body Non-isothermal Analysis for Friction Welding

Now, it is available to analyze the 2D multi-body non-isothermal friction welding problem, which is one of the joining processes. Fig. 1.26 illustrates the analysis results.

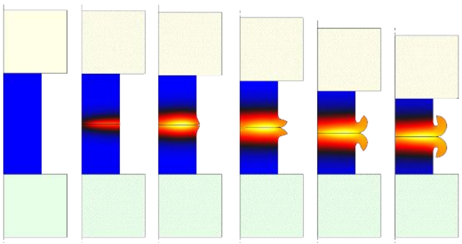


Fig. 1.26 2D analysis for friction welding

1.3.6 Load Graph (Accumulated Load for All Stages)

In the case of the metal forming press machines for automatic multi-stage hot/cold forging, every load acting in each stage is applied on the equipment simultaneously. Now, one can check not only a graph of a load for each process, but also an accumulated load graph of all processes at once. Fig. 1.27 illustrates the graph of load vs. time, which has a curve of load per each stage and a curve of an accumulated load.

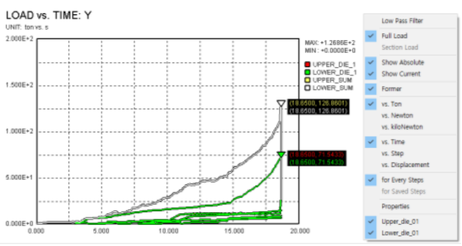


Fig. 1.27 Option to see the load graph

1.3.7 Calculation of Minimum Length between Die and Workpiece

Under-fills can be easily found when one executes a simulation for complex shape parts. To calculate the size of the under-fills or the distance between die and workpiece, it requires a few extra procedures. In order to avoid the inconvenience in using this tool, all AFDEX users can now check the distance between die and workpiece easily. Fig. 1.28 illustrates the calculation result of the minimum distance between the die and the workpiece based on the deformation analysis.

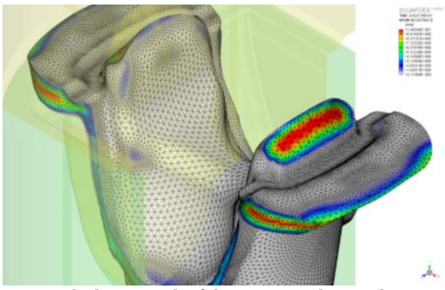


Fig. 1.28 Calculation result of the minimum distance between die and workpiece

2. Successful Application Cases of AFDEX

The followings are successful application cases of AFDEX used recently. For more details, please refer to the material presented in The Korean Society for Technology of Plasticity (KSTP) conference Fall 2019.

2.1 Crankshaft Die Structural Analysis

Figure 2.1 illustrates the die structural analysis result during crankshaft hot forging process. The simulation result was used for prevention of die crack occurring on the region where high-effective stress is applied.

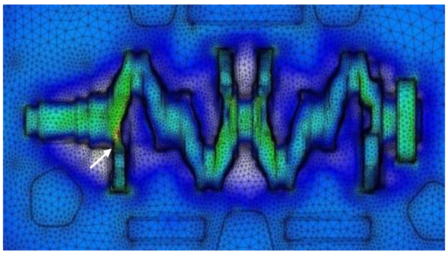


Fig. 2.1 Effective stress distribution on die during crankshaft hot forging process

2.2 Optimal Design for 3D Die Shape

Details about the optimal design was already mentioned in Newsletter 2019 Q1. For generalization of the optimal design for 3D processes, the die shape should be parametrized. A research regarding this have been continued and will be developed gradually. This content was published through Int. J. Auto. Tech in 2019. Figure 2.2 shows the case of the 3D die shape optimal design of an enclosed-die forging process, where the design variables include geometric dimensions of die and material. The optimal design was able to reduce 8% from the original weight of a material, and 5% from the original forming load.

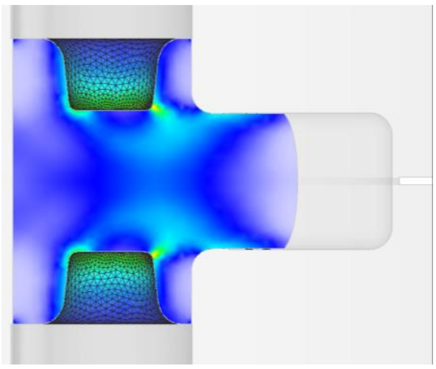


Fig. 2.2 3D Optimal process design (Ball nut closed die cold forging)

2.3 Plate Forging Process Design

The plate forging process (forming plate or sheet using forging methods) is being applied for the purpose of omitting material removing process. When a workpiece whose thickness has changed drastically through the plate forging, is formed, the process design often ends in failure because bending occurs due to a difference in thickness. For this purpose, it is highly effective to optimize the process design using the metal forming simulation. Figure 2.3 compares the predictions of different process design tryouts by simulation.

Fig. 2.3 FE predictions for finding acceptable process design

2.4 Experimental and Numerical Acquisition of Material Constants for Grain Size Prediction

Material constants that have the characteristics of a material and the proper constitutive model are essential to predict the grain size during hot forging. However, it requires high cost and expertise to obtain those material constants. AFDEX researchers have developed a method for determining the material constants at comparatively low cost (J. Mater Res Technol.(2019, Vol. 8). Figure 3.4 shows an example which is applied in real process using the material constants obtained. To get the material constants, the results of high-temperature compression test and the grain size information of the model process obtained experimentally are needed.

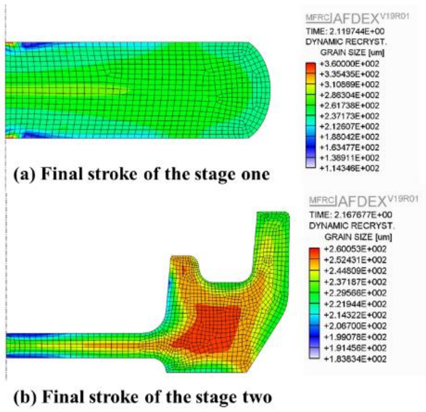


Fig. 2.4 Predicted DRX grain size (μm)

3. Main Events of 2019

3.1 Domestic Events

3.1.1 Korea Metal Week 2019

Dr. Hokeun Moon participated in Korea Metal Week 2019 held in Korea on June 19-22, 2019. He conducted technical seminar about the metal forming process design and application using CAE.

Fig. 3.1 Korea Metal Week 2019 exhibition

3.1.2 GISPAM 2019

GISPAM 2019 was held at Gyeongsang National University for five weeks starting from 15th July. GISPAM is an international cooperation program, started and financially supported by the government of the State of Mexico six years ago. In this year, 30 scholarship students in the State of Mexico, 2 university students from Universiti Teknologi MARA, Malaysia, and 10 Korean undergraduate and graduate students participated.

Fig. 3.2 GISPAM 2019 after evaluation of the program

3.1.3 MFCAE 2019

MFCAE 2019 was held at Jinju MBC Convention from 8 to 9 August. At this event, undergraduate sessions, graduate student sessions, user sessions, developer sessions, and professional training sessions were held. Also, Dr. Mansoo Joun delivered a special lecture about the modeling technology of the metal forming process.

Fig. 3.3 MFCAE 2019

3.2 International Events

3.2.1 ASIA FORGE MEETING 2019

The 7th ASIA FORGE Meeting 2019 was held during January 19-20, 2019 at Mahabalipuram, India. MFRC attended the expo as a sponsor.

Fig. 3.4 AFM 2019 exhibition

3.2.2 Forge Fair 2019, USA

MFRC participated in Forge Fair 2019 held at Cleveland, Ohio on May 21-23, 2019. Forge Fair is North America's largest forging industry trade show, with more than 1,600 attendees. MFRC exhibited AFDEX and also spoke about the intelligent metal forming simulation focused on the analysis accuracy.

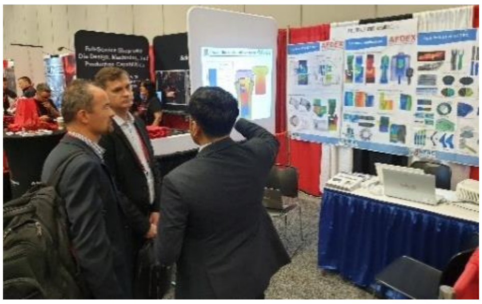


Fig. 3.5 Forge Fair 2019 exhibition

3.2.3 ICPMMT 2019

ICPMMT 2019 was held in Kenting, Taiwan from May 24, and MFRC was invited for the expo. In this event, Dr. Mansoo Joun gave an invited keynote speech, which was about "Accuracy of metal forming simulation."

Fig. 3.6 ICPMMT 2019 keynote presentation

3.2.4 NUMIFORM 2019

The event was held for June 23-27, 2019 at New Hampshire, USA. Some of the researchers from MFRC presented their work in the conference which is attended by the field's top thought leaders. The main theme of MFRC's presentations in NUMIFORM was process design optimization in metal forming processes. MFRC had a close Q&A time for Altair-AFDEX users or global users in our booth. The exposition was run together with Altair because AFDEX is an APA software of Altair.

Fig. 3.7 NUMIFORM 2019 exhibition

3.2.5 MetalForm China 2019

MFRC participated in MetalForm China 2019 exhibition held in Shanghai, China (Shanghai New International Expo Center, SNIEC) for three days from July 17 to 19, 2019. In this Expo, MFRC had collaborated with BRIMET, our agent in China.

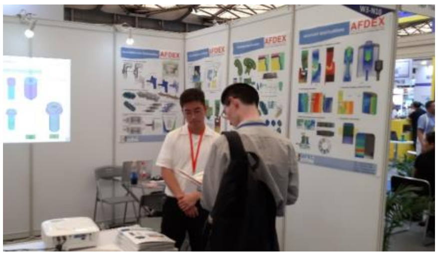


Fig. 3.8 MetalForm China 2019 exhibition

3.2.6 ICAME 2019

MFRC attended the 6th International Conference on Advances in Mechanical Engineering 2019 (ICAME 2019) as a Gold Sponsor in Kota Kinabalu, Malaysia at August 14-16, 2019. The theme for the 2019 edition of ICAME was "Engineering for Humanity", emphasizing the role of engineering in providing technologies to fulfill the needs of modern humanity. Industry experts from Malaysia, Germany, Japan and Korea discussed on various topics such as human capital development in the era of Industry 4.0, advanced manufacturing technology and simulation and design applications within the automotive industry. In conjunction with ICAME 2019, two MOUs (MARii-MFRC and UiTM-MFRC) were signed.

Fig. 3.9 Signing MOU between MARii and MFRC

3.2.7 Visiting Indian Forging Companies

MFRC member visited prominent Indian forging companies in Belgaum, Nashik and Pune, during the third week of September 2019. The visit was very helpful to understand their needs and provide them innovative and efficient solutions as well as to get some new ideas for AFDEX improvement. A two-day training program was also conducted to introduce AFDEX and its world of capabilities.

Fig. 3.10 Meeting for finding some new idea to model a special shearing process

3.2.8 Global ATC 2019

Altair's Global Technology Conference - GATC was held in Detroit, USA on 10th and 11th of October 2019. The show, a major PLM technology exhibition, brought together a community of global tech leaders. MFRC participated in GATC as an exhibitor-sponsor and introduce some latest features of AFDEX during this event.

Fig. 3.11 GATC 2019 exhibition

3.2.9 JSOL CAE Forum and AFDEX Technical Consultation

JSOL CAE Forum 2019 was held in Tokyo, Japan (Tokyo conference center Shinagawa) for three days from November 6 to 8. Dr. Mansoo Joun presented the metal forming simulation technology for multi-body and optimal design. In this forum, also, there was AFDEX technical consultation for AFDEX users.

Fig. 3.12 JSOL CAE Forum presentation