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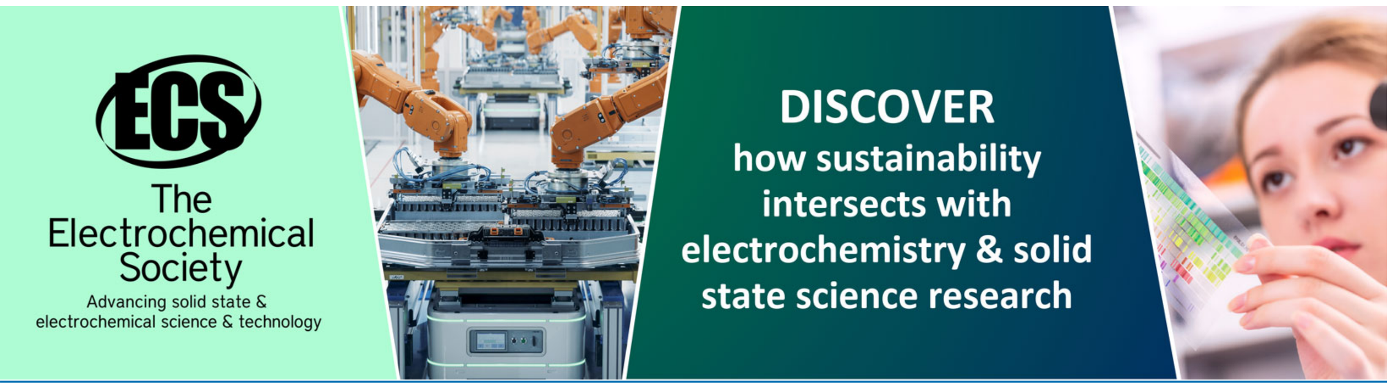

Development of plug-ins for bridging variables between advanced finite element codes and 'UMMDp'

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Abstract. For advanced finite element codes, we can add original material models by programming ourselves. On the other hand, as for implementation methods, we need unique technique in each advanced finite element codes, and there was a problem that it is difficult to implement unless we fully understand the procedure of these codes. Therefore, the Japan Association for Nonlinear CAE (JANCAE) has started to implement anisotropic yield functions independent of advanced finite element codes in its working group activities, and has created a subroutine library "UMMDp". The "UMMDp" library is connected to each advanced finite element codes with "plug-ins", and variables are bridged. In this report, we first explain the concept of "plug-ins" development and verification method in implementation. Next, we introduce some examples that we implemented "UMMDp" into the advanced finite element code "LS-DYNA" via the plug-ins. By comparing with the built-in yield function, we will explain that "plug-ins" is working properly and the usefulness of "UMMDp".

1. Introduction

These days we conduct numerical analyses using advanced finite element codes. In the field of structural analysis, the application targets of advanced finite element codes widely range from crash analysis, metal forming analysis, drop analysis, and so on. In order to meet the demands of users' requests, the advanced finite element software periodically updates [1] .

This updates are remarkable, especially with regard to material models, which allow uses to not only deal with newly developed materials, but also express the physical phenomena of materials as closely as possible. New yield functions have been frequently proposed in major papers[2][3][4][5]. Users of advanced finite element software expect to use the new functions at an early stage, but in practice, users wait for developers to implement them.

Early implementation of a new material model is highly expected in the field of sheet metal forming analysis. This is because, in this field, anisotropy has a great influence on formability, even though its importance is still not considered in crash analyses. For that reason, many anisotropic yield functions have been proposed to fit the actual physical phenomena. However, in order for a new material model (anisotropic yielding function) to be implemented into advanced finite element software, it needs to be sufficiently validated.

Users who cannot wait to implement these useful anisotropic yield functions may wish to implement the material model themselves. Normally, advanced finite element software has functions that implement user-defined subroutines[6]. However, implementing these functions is not easy, as there are many specific manners for each advanced finite element software.

Therefore, the Japan Association for Nonlinear CAE (JANCAE) has started to implement anisotropic yield functions independent of advanced finite element codes in its working group activities, and has created the unified material model driver for plasticity subroutine library UMMDp. The UMMDp is connected to each advanced finite element code with "plug-ins" and variables for processing the anisotropic yield function are bridged. As the UMMDp is independent, it is possible for users to create it even if they do not understand how to write in advanced finite element code. However, they cannot create plug-ins unless they fully understand the usage of these codes. Therefore, major structural analysis software vendors in Japan cooperated with JANCAE to develop the plug-ins. We are in charge of the development of plug-ins for LS-DYNA.

2. About plug-ins

2.1 Concept of plug-ins

In this section, we explain the role of the plug-ins. The UMMDp, which can deal with many material models, is implemented the stress integral method in which, basically, the incremental strain components are passed from a main routine and the integrated stress components are returned to a main routine. The plug-ins plays the role of bridging these arguments between the main routine of each FE code and the UMMDp and its interface follows the way of each FE code.

Figure 1 shows framework of plug-ins in the case of LS-DYNA.

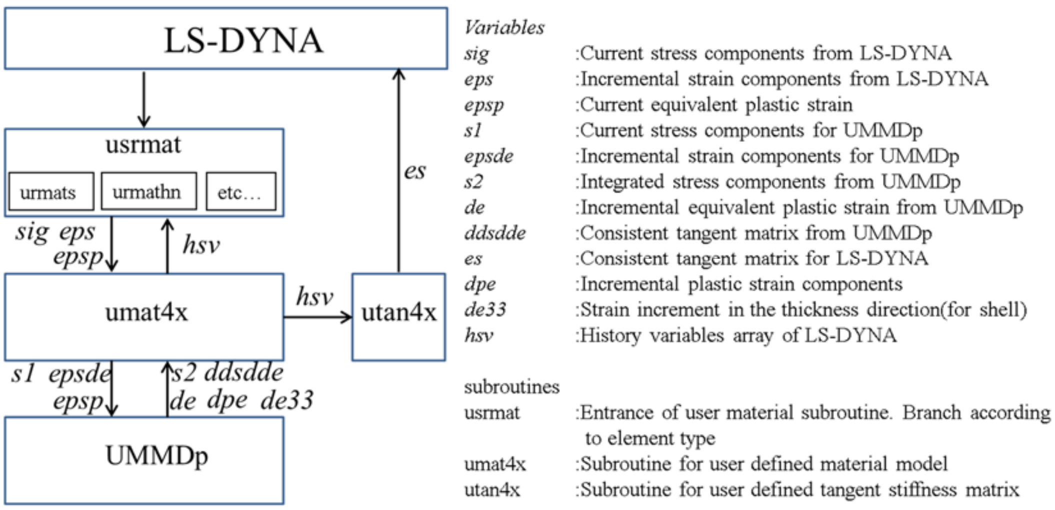


Figure 1. Framework of plug-ins for LS-DYNA.

The number of stress and strain components needs to be noted. For example, a shell element of LS-DYNA have five components (xx, yy, xy, yz, zx) basically, in spite of, in most FE codes, a thin shell element have three components (xx, yy, xy) and a thick shell element have five components (xx, yy, xy, yz, zx). Therefore, for bridging from the LS-DYNA shell element to the UMMDp thin shell element, it is necessary to ignore the out-of-plane shear component. Conversely, the out-of-plane shear stress increment is determined by elastic prediction.

The consistent tangent matrix *ddsdde* is necessary for the implicit method, it is calculated in UMMDp. However, in the case of using the explicit method, LS-DYNA does not require the consistent tangent matrix *ddsdde*. On the other hand, in the case of using the implicit method, the matrix *ddsdde* is usually calculated in subroutine utan4x. Since the consistent tangent matrix has already estimated in UMMDp, the matrix *ddsdde* is stored as a history variables array *(hsv)* in subroutine umat4x, and then the consistent tangent matrix array (*es)* in subroutine utan4x is relocated from the array *hsv*.

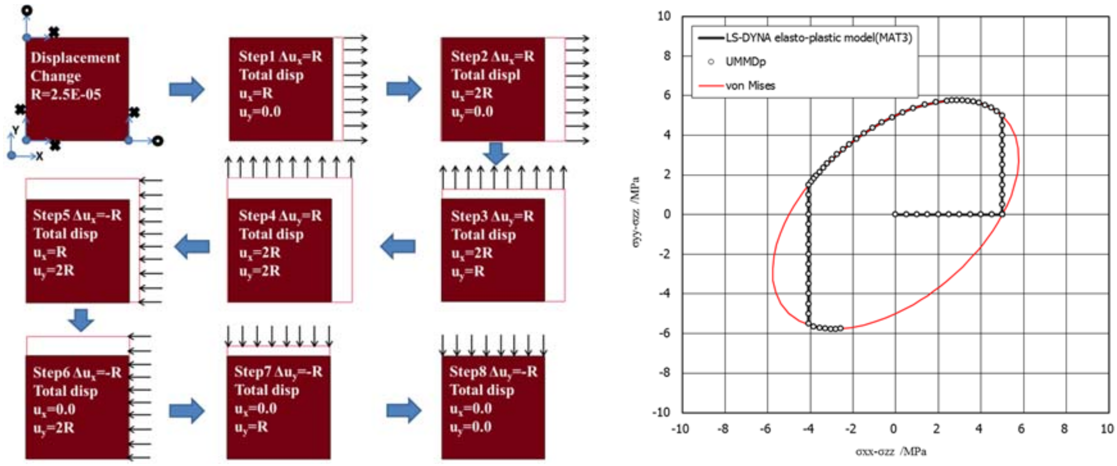
2.2 Verification test for plug-ins

In order to check whether the plug-ins worked properly, we used the example described in NAFEMS[7]. We used the one element verification test, and compared the stress paths of the UMMDp and built-in yield function. Table 1 shows material constants for verification test.

Table 1. Material constants for verification test.

Young's modulus	E =	250	GPa
Poisson's ratio	ν =	0.25	
Yield stress	σ_Y=	5	MPa
Yield function	σ_e=	Von Mises	

We have verified plane strain, plane stress, shell and solid element. Here, the case of plane strain element is shown using von Mises material with comparing elasto-plastic model of the LS-DYNA and UMMDp. Figure 2 shows boundary condition of this test and the result. From the result, UMMDp and LS-DYNA draw the identical yield loci. We have confirmed plug-ins is working properly.



(a) Boundary conditions (b) Yield locus

Figure 2. Simple verification test of plug-ins for LS-DYNA

3. Numerical analyses example

In order to check whether the UMMDp can be available to practical problems, we performed calculations on two examples of sheet forming process. Here, the fact whether the UMMDp and the plug-ins work properly is confirmed using the anisotropic yield function implemented into LS-DYNA and UMMDp. In this example, we use the following material constants:

Table 2. Material constants for numerical analyses.

Young's modulus	E =	2.00E+05	MPa
Poisson's ratio	ν =	0.3	
Yield Function	σ_e=	Barlat YLD2000-2d	
Flow stress $\sigma_Y=K(\bar{\varepsilon}^p+\varepsilon_0)^n$	K =	541	MPa
	ε_0=	3.60E-03	
	n=	0.249	

α1	0.973738	α6	0.776576
α2	1.062062	α7	0.983219
α3	0.843006	α8	1.121953
α4	0.927158	M	4.893605
α5	0.941647		

3.1 Deep drawing with spherical punch

We carried out the deep drawing analysis as the first example. The analysis model is shown in Figure 4. The deep drawing with spherical punch can simultaneously generate stress states corresponding to the first, second, and fourth quadrants of the principal stress plane. It is a suitable example for checking the validity of the implemented code.

Figure 3. Numerical model of the deep drawing with spherical punch.

Figure 5 shows the numerical result of the deep drawing with spherical punch. In this figure, the contour of the "Von Mises Effective stress", "equivalent plastic strain" and "thickness reduction ratio" are shown. We are able to obtain results with nearly equal tendencies with UMMDp and LS-DYNA built-in.

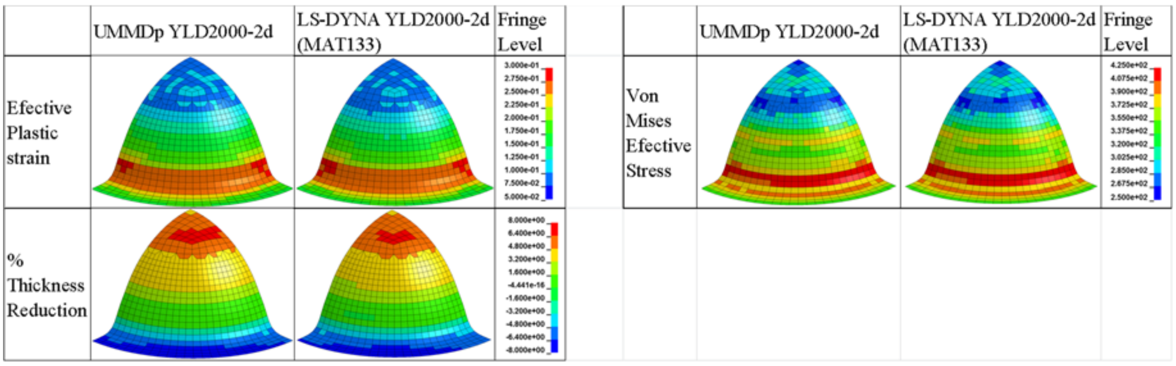


Figure 4. Numerical result of deep drawing with spherical punch.

3.2 S-Rail (Shape is based on Numisheet 96)

In order to confirm the application to practical problems, we carried out a forming analysis of S-rail. We used the benchmark data of Numisheet 96 for the shape and analysis conditions. Figure 6 shows forming image of this analysis.

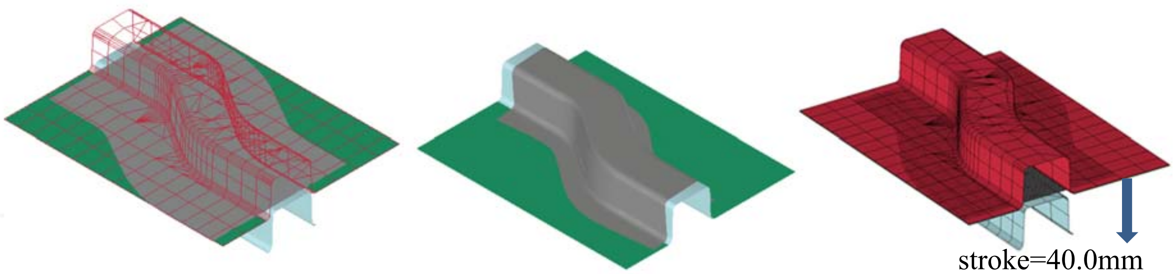


Figure 5. Numerical model of the S-rail.

Figure 7 shows the forming force curve of the S-rail. From these curve of the forming force graph, it can be said that the forming event is almost equivalent in the two analyzes.

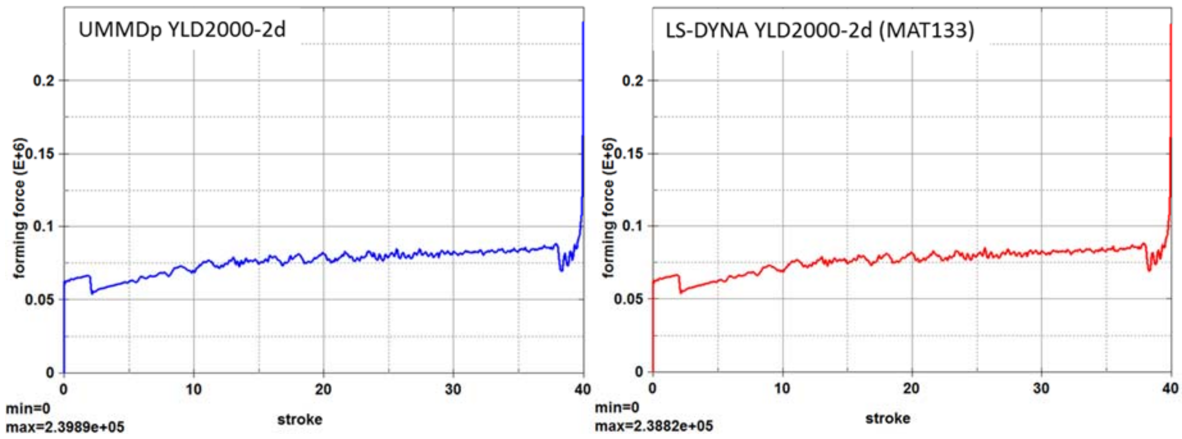


Figure 6. Forming force curve of the S-rail.

The maximum forming force at the bottom dead center is as follows,

UMMDp	YLD2000-2d	: 2.3989E+05 [N]
LS-DYNA	YLD2000-2d(MAT 133)	: 2.3882E+05 [N]

Since there is no difference in the maximum forming force at the bottom dead center, it can be said that the stiffness of the blank material returns a substantially equivalent value to the main routine.
The CPU times of each were as follows,

UMMDp	YLD2000-2d	: 741 seconds
LS-DYNA	YLD2000-2d(MAT 133)	: 690 seconds

Although LS-DYNA was slightly faster, it was judged that there was no problem in practical use. From these results, UMMDp is applicable to practical problems.

Note that ITER = 1 is set in the LS-DYNA YLD2000-2d (MAT133) in order to fair the convergence calculation of the yield stress. In this material model, ITER provides an option of using three secant iterations for determining stress return and leads to a more accurate prediction of shell thickness changes.

Figure 8 shows the numerical result of S-rail. In this figure, the contour of the "Von Mises Effective stress", "equivalent plastic strain" and "thickness reduction ratio" are shown. We can see the result of UMMDp agree with that of LS-DYNA built-in model.

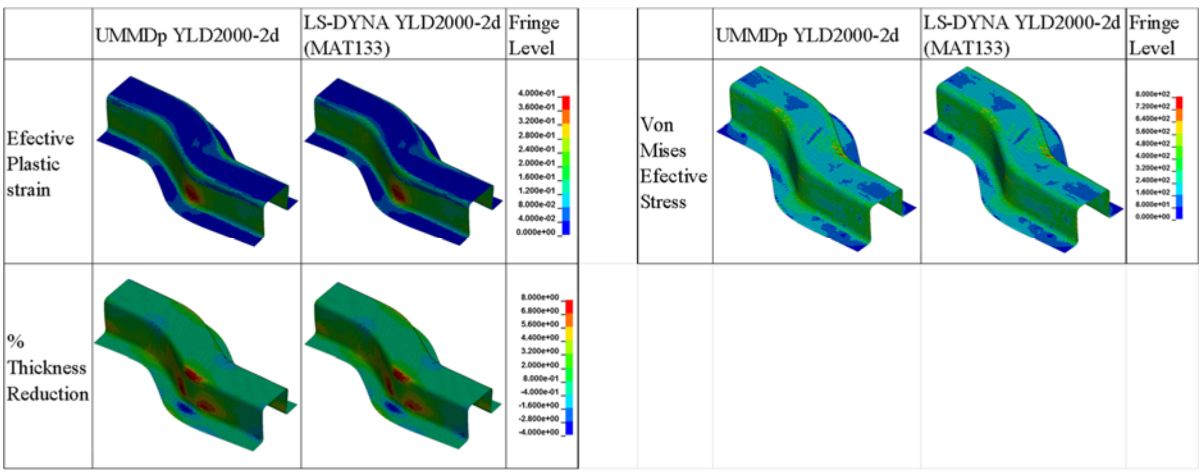


Figure 7. Numerical result of S-rail.

4. Conclusion

We have developed "plug-ins" for connecting the "UMMDp" with advanced finite element software. We conducted a verification one element model test proposed by NAFEMS and confirmed that LS-DYNA and the UMMDp were connected properly. We carried out numerical analyses of the deep drawing and S-rail stamping as a practical example, and confirmed that the "plug-ins" can available for practical use.

Acknowledgements

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