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# DEVELOPMENT OF EFFICIENT FEM ANALYSIS METHOD USING EQUIVALENT 2D MODEL FOR LINEAR FRICTION WELDING ANALYSIS

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**Abstract.** LFW(*Linear Friction Welding) is the one of the smart industrial method matching to SDGs concept. It only needs a pair of blanks with no other assisting materials. This technique is now widely used in the Aeronautical, Automobile and other mechanical industries. In this paper we introduce an efficient LFW analysis method with 2D FEM model of LS-DYNA. In conclusion, analysis showed good correlation to the experimental results of the LFW process.*

## 1 INTRODUCTION

LFW is a bonding method by heating a pair of blanks with each lateral vibration and normal pressure. Blanks are heated just before the solution phase and realize solidified bonding. So the blank material structures keep original performance causing smooth strength distribution between HAZ and surrounding zones.

In general analysis models of LFW are generated with 3D precise meshes of long width for its lateral vibration action along the contact faces. In consequence the analysis model needs much calculation time and long developing period to decide optimum design.

In this paper we introduce a 2D model for LFW analyses constructed with 2D plane-strain element meshes using LS-DYNA(Large deformation analyses were well carried out by LS-DYNA [1]). To realize equivalently of the effect of lateral vibrations to this 2D model we introduced some unique FEM techniques. Lastly we got good coincidences between the model and the experiment in the blank deformation mode.

## 2 CONDITIONS OF EXPERIMENT AND DEFORMATION RESULT OF LFW

Fig. 1 and Fig. 2 show the experimental conditions of an example of LFW experiment.

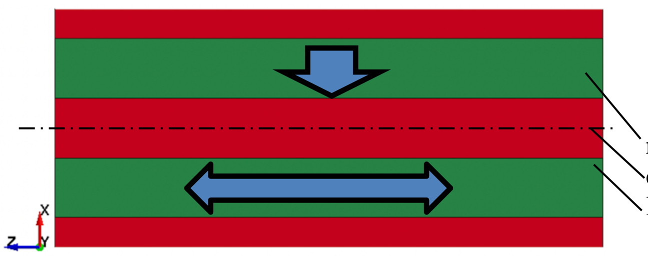



Fig. 1 Test rig (In-plane view)

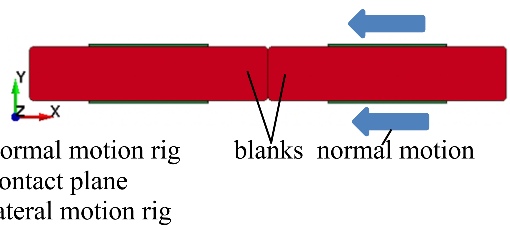



Fig. 2 Test rig (Side view)

Fig.1 shows the in-plane view of the experiment rigs. Upper side blank is pressed normally and lower side blank is vibrated laterally. In this experiment blank material is High-Tensile-Strength-Steel (980MPa class) and the thickness of the blanks are selected to 1.8mm (t1.8) and 2.3mm (t2.3). Fig. 2 shows the side view of the rigs. Both test-rigs are spaced considering deformation stroke by heating. Experimental conditions are showed in Fig. 3 and Fig. 4.

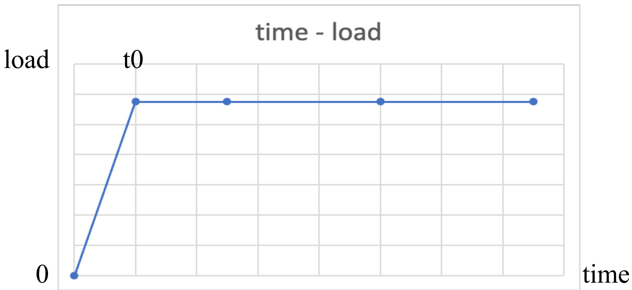


Fig. 3 Normal load on the right blank (Fig. 2)

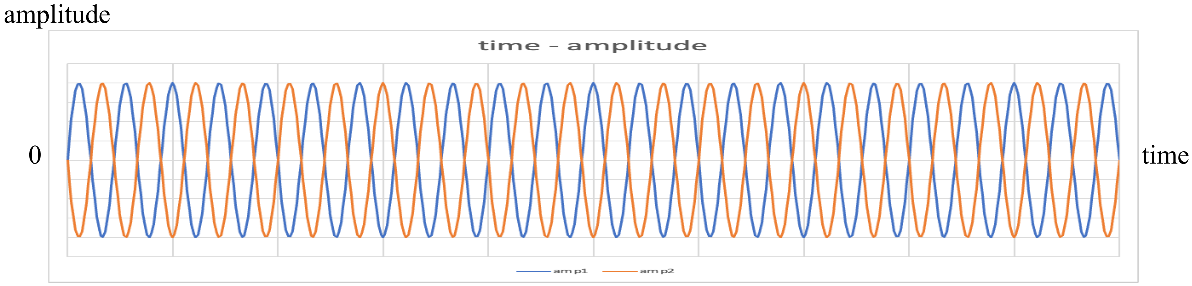


Fig. 4 Vibrations to the left blank (Fig. 2)

Fig.3 shows the setting pressure to the contact surface of the blanks. The pressure reaches the maximum level at t0 and keeps the equal level to the end of large deformations of the blanks. Fig. 4 indicates the initial phase of the left-side blank vibration. Up to the end equal vibration amplitude and frequency are kept on equal value.

For this model one more load is necessary for the blanks. But the necessity and the loading method are showed later.

Blank deformations through the experiments are shown in Fig. 5 and Fig. 6.

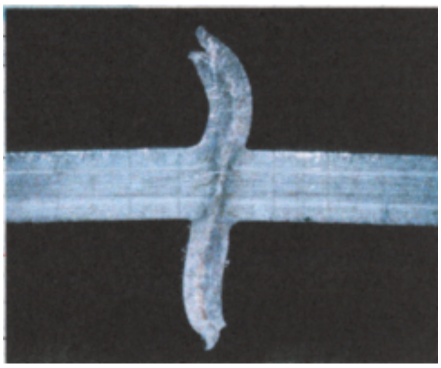


Fig. 5 Deformation mode of t1.8 blank

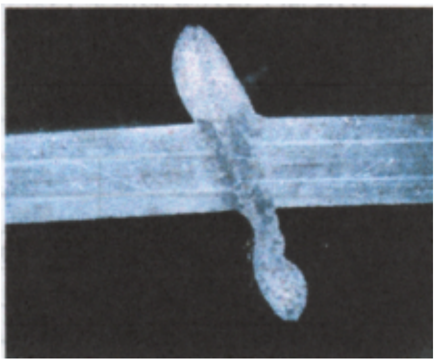


Fig. 6 Deformation mode of t2.3 blank

## 3 MODELING METHOD OF 2D ANALYSIS MODEL

### 3.1 ANALYSIS MODEL

LFW analysis model construction for this problem is shown in Fig. 7(3D) and Fig. 8(2D).

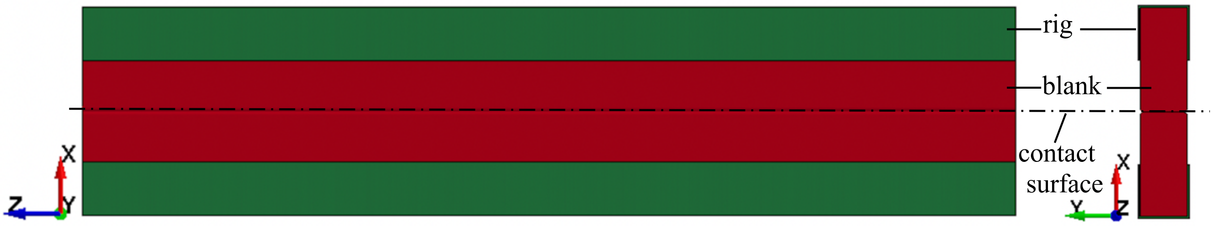
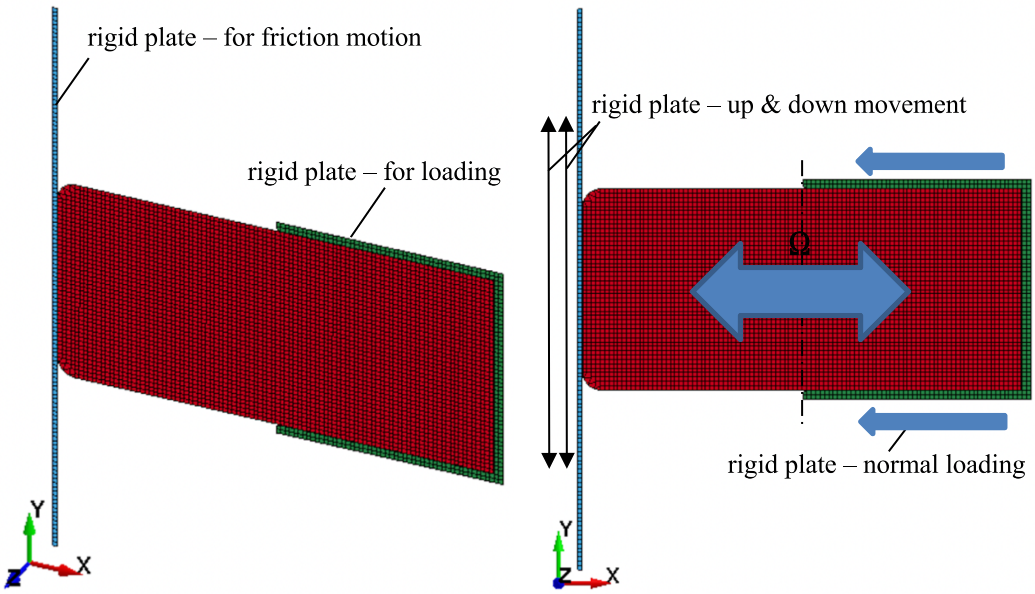



Fig.7 LFW 3D analysis model




a. Oblique view of the 2D model b. Side view of the 2D model

Fig.8 LFW 2D analysis model

### 3.2 CONCEPTS OF DEVELOPING OF THE 2D ANALYSIS MODEL

We adopted the ROM(Reduced Order Model) to get high speed of calculation time and low period of design optimization. Following concepts were adopted for this ROM.

1. Blanks deformations are considered in plane-strain condition with average-time.

2. Lateral vibration frictional loads are equivalently converted to vertical frictional loads because heat generation is more important than frictional loading.

3. Upper-mentioned vertical frictional vibrational movements are equivalently divided to two crossed vibrational movement – up & down plus down & up - of half energy.

4. Because that the experimental deformation process is mirror-symmetry blank versus blank deformation can be changed to blank versus rigid surface deformation.

5. On the blank a certain level centrifugal force field Ω is set. This Ω produces pressure stress field which is supposed to be produced by shearing force along the contact surface.

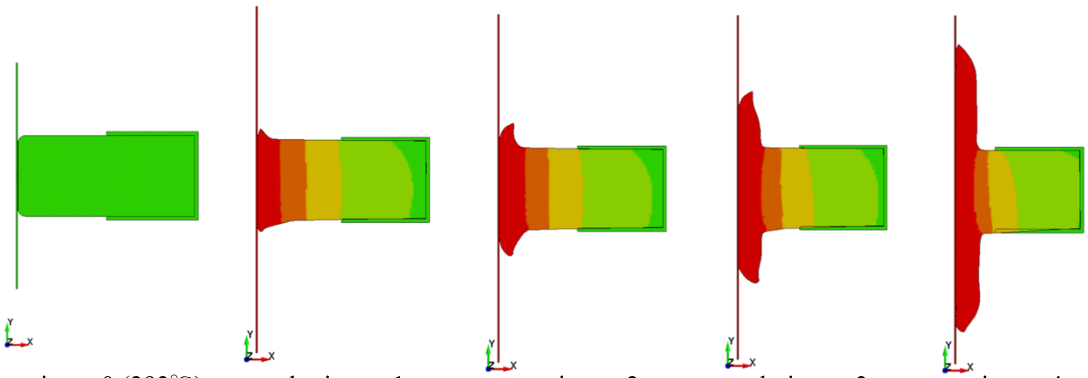
The reason of adoption of 3rd concept is that ordinal one-way up & down frictional loads has possibility of occurrences of blank bending resonances. The 5th concept is introduced from the back & force shearing forces on the contact plane which axis is neglected in this model. And if this force field Ω (Fig. 8b) is not provided the blanks produce much curly deformations.

With these concepts we can use the 2D model equivalently instead of the 3D model.

## 4 ANALYSIS RESULTS

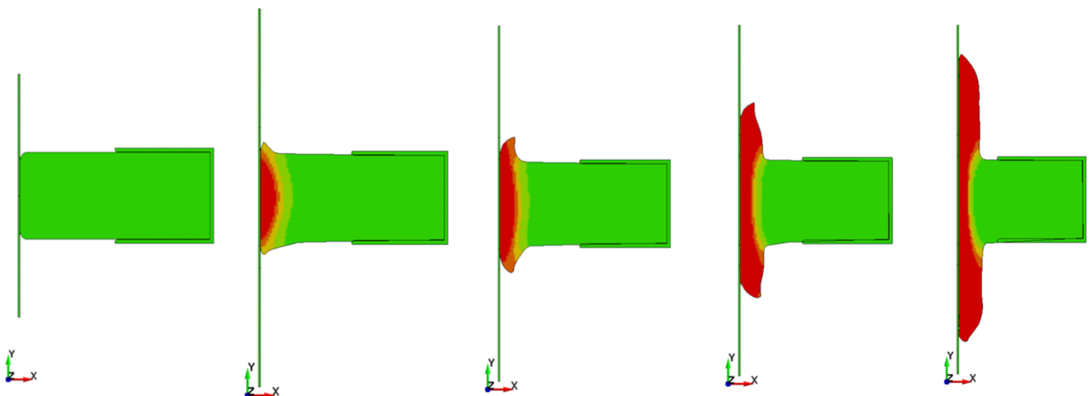
### 4.1 2D Model analysis results

Fig. 9 and Fig. 10 show the 2D model analysis results. According to these results we can see how the deformation proceed and how the curly flare rise and fall.



a. time ; 0 (293℃) b. time ; t1 c. time ; t2 d. time ; t3 e. time ; t4

Fig.9 Analysis results – deformations with temperature distribution (max. range ; 1200℃)

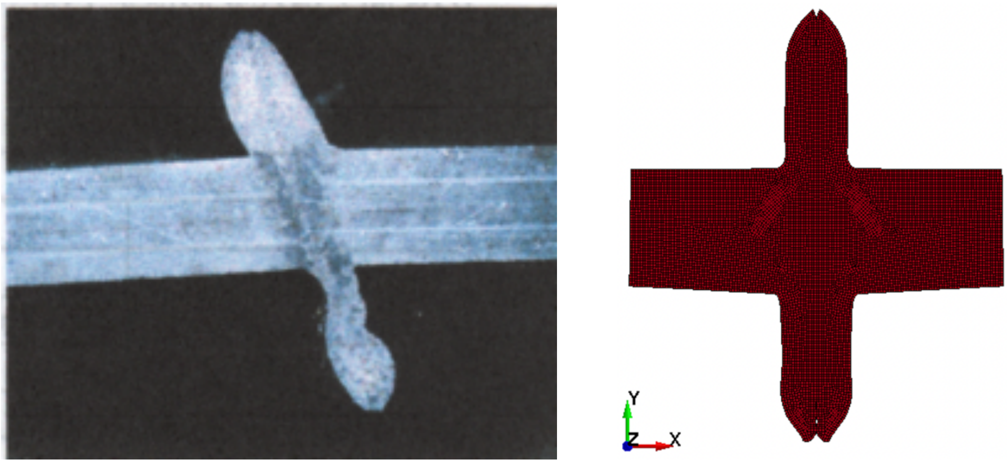


a. time ; 0 b. time ; t1 c. time ; t2 d. time ; t3 e. time ; t4

Fig.10 Analysis results – deformations with plastic strain distribution (max. range ; 5)

## 4.2 Comparison to the experiment result

Fig. 11 shows the comparison of the deformed shape between experimental and analysis results of t2.3 blank. These blank deformations are similar to those in the case of t1.8.




a. Experimental result b. Analysis result

Fig.11 Comparison of experimental and analysis results – blank final deformations

In the Fig.11b analysis result was copied to mirror-symmetry of Fig. 9 or Fig. 10 analysis results. Deformed shapes of both blanks are similar to each other. In the experimental result bonded surface is somewhat oblique because of the initial shearing angle of right and left blanks.

One item which we should consider further will be the bonding condition between left and right blanks in the analysis results. But it can be decided by analyzing the outputs of temperature and normal stresses.

## 5 CONCLUSIONS

This paper proposed a unique technique for LFW 2D analysis model with LS-DYNA. We prepared following premises which is necessary to make model reduction from 3D to 2D.

1. Blanks can be thought in the plane-strain condition with average-time.

2. Lateral vibration of contact surface can be converted to vertical vibration.

3. Upper-mentioned vertical vibration was split to twin reversive vertical vibration escaping blank bending resonances.

4. Because that the experimental deformation process is mirror-symmetry blank versus blank deformation can be changed to blank versus rigid surface deformation.

5. A certain level centrifugal force field was set on the blank to produce contact pressure appeared by shearing contact forces.

Comparison between experimental and analysis results indicated good co-relation to each other in the deformation mode. Besides we could see the blank deformation process and the blank curly flare rise and fall.

This time we provided an example of 2D analysis model for LFW analysis, but 2D analysis models can effectively be used to many other kind of machine-parts development [2,3]. For other examples, we had already developed some techniques on RFW(Rotary Friction Welding) analyses.

From a standpoint of MBD (Model Based Design), it is recommended to use simple but speedy analysis model (2D model) and 3D full-size model according to the developing phase.

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