OPTIMUM BLANK DESIGN FOR DEEP DRAWING USING INTERACTION OF HIGH AND LOW FIDELITY SIMULATION

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Summary The design optimization system is developed using the interaction of high- and low-fidelity finite element simulations of a deep drawing process, and the multipoint approximation technique based on the iterative response surface building. The system has been applied to the optimum blank design for deep drawing process of a rectangular box to determine the optimum initial blank design that minimizes the waste of material. The blank design was optimized successfully in remarkably short computational time.

INTRODUCTION

One of the major drawbacks of numerical optimization for sheet metal forming process is its too long computational time. Our target is quick and effective optimization system for process design of sheet metal forming. In this work, the optimization system is developed using the interaction of high- and low-fidelity finite element simulations of a deep drawing process, and the multipoint approximation technique [1, 2] based on the iterative response surface building. Approximation functions and a weighting scheme are introduced in order to correct the low-fidelity responses so they can be treated as high quality approximations. The approximated problem is then solved by the multipoint approximation technique, hence there are two levels of approximation in the optimization process to reduce the computational time. The system has been applied to the optimum blank design for deep drawing process of a rectangular box. The optimization problem is to determine the optimum initial blank design that minimizes the waste of material. The validity of the developed optimization technique is discussed based on the obtained results.

OPTIMIZATION BASED ON THE INTERACTION OF HIGH AND LOW FIDELITY SIMULATION

An iterative optimization procedure requires a large number of high-fidelity process simulations (e.g. FE simulations using fine mesh) to obtain accurate responses of the objective and constraint functions, and it takes quite a long time. Therefore, in the present optimization procedure, the low-fidelity simulation (e.g. FE simulation using coarser mesh), which is computationally less expensive, is used as substitution of the original high-fidelity one. The approximation functions:

$$\tilde{F}(\mathbf{x},\mathbf{a}) = \tilde{F}(f(\mathbf{x}),\mathbf{x},\mathbf{a}) \qquad (1)$$

are built based on numerical experiments and used to correct the low-fidelity responses. Here, **a** is the set of tuning parameters, **x** the vector of design variables and $f(\mathbf{x})$ the low-fidelity responses, respectively. Several types of simple functions [2] are available as the approximation functions (1). The high-fidelity simulation is used only for the numerical experiments to build the approximation functions (1) prior to optimization and validation of the solution.

The optimization procedure based on the interaction of high and low fidelity simulation is described as follows:

1. Both of the high- and low-fidelity simulations are carried out according to a selected plan of experiments.
2. The approximation functions (1) are built based on the results of the above numerical experiments.
3. The optimization problem is solved using the low-fidelity responses corrected by the approximation functions (1), and the optimum design of the present step, **x***, is obtained. Multipoint approximation method [1, 2] is employed to solve the optimization problem. In this optimization process, the original high-fidelity simulation is never used.
4. The high- and low-fidelity simulations are carried out for the obtained optimum design **x***.
5. The obtained optimum design **x*** is validated.
6. If the solution **x*** is not acceptable, the plan of experiments is modified using the obtained design **x*** and the approximation functions are rebuilt. Weight coefficients are introduced into the least square fitting to rebuild the approximation functions so that the contribution of design points around the solution **x*** becomes comparatively higher. Then the optimization for the next step is carried out.
7. If the solution **x*** is acceptable, it is the final solution and the optimization procedure is completed.

OPTIMUM BLANK DESIGN FOR DEEP DRAWING PROCESS OF A RECTANGULAR BOX

The developed optimization technique is applied to the optimum blank design for deep drawing process of a rectangular box. In deep drawing process, the flange of the product is often trimmed after the drawing process to obtain the desired product shape (see Fig. 1), and the trimmed material is wasted. Since the flange shape of the product is strongly affected by the initial blank design, the optimization problem is to determine the optimum initial blank design that minimizes the waste of material, as shown in Fig. 2. Therefore, the initial blank shape is treated as design variables, and

the objective function is the amount of wasted material, i.e. area α shown in Fig. 2. Two types of blank design, i.e. corner-cut type and B-Spline type are used. They are defined by four design variables. It is well known that too large a blank induces excessive local thinning or fracture of the sheet. On the other hand, when a blank is too small, the contour of the flange penetrates the trimming line. To avoid these defects, two constraints, i.e. the thickness constraint and the contour constraint are introduced. Dynamic-explicit finite element code (PAM-STAMP) and Simplified static-implicit finite element code (PAM-QUIKSTAMP) are used for the high- and low-fidelity simulations, respectively. Besides, the low-fidelity model has only about 120 elements and needs about 10 seconds for one simulation, while the high-fidelity model has about 1100 elements and requires about 150 seconds.
Fig. 3, Fig. 4, Table 1 and Table 2 show the optimum solution in comparison with the solution obtained by using only high-fidelity simulation. The 1st step solution based on the interaction of high and low fidelity simulation is not acceptable since the quality of the approximation function is not good enough. In the 2nd step optimization using weighting scheme, the quality of the approximation function is improved and a successful blank design, which is almost the same as the original high-fidelity solution, is obtained. In terms of computational time, the developed optimization technique has the great advantage over the original high-fidelity optimization as shown in Tables 1 and 2.

CONCLUSION

The presented optimization system using high and low fidelity simulation is found to be effective for the quick determination of the optimum blank design for deep drawing process. Optimum solution is obtained in remarkably short computational time. This is an encouraging result for the construction of optimization system for various sheet metal forming processes.

References

[1] Toropov V.V.: Simulation Approach to Structural Optimization. *Structural Optimization* **1**:37-46, 1989.
[2] Toropov V.V., van Keulen F., Markine V.L., Alvarez L.F.: Multipoint Approximations Based on Response Surface Fitting: A Summary of Recent Developments. *Proc. of 1st ASMO UK/ISSMO conference*:371-380, 1999.

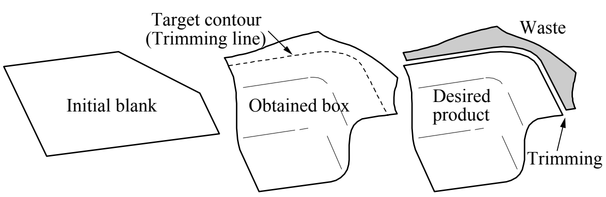

Figure 1. Deep drawing process of a rectangular box

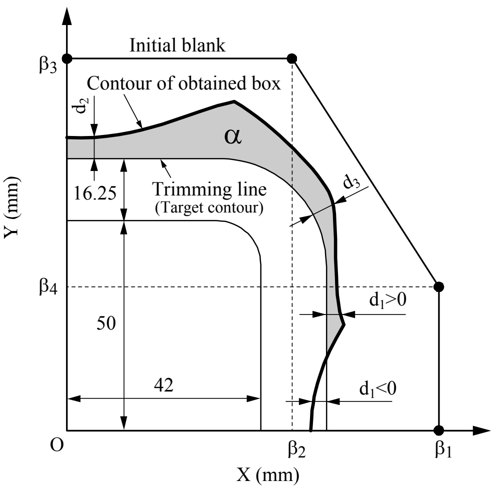

Figure 2. Optimization problem of deep drawing process

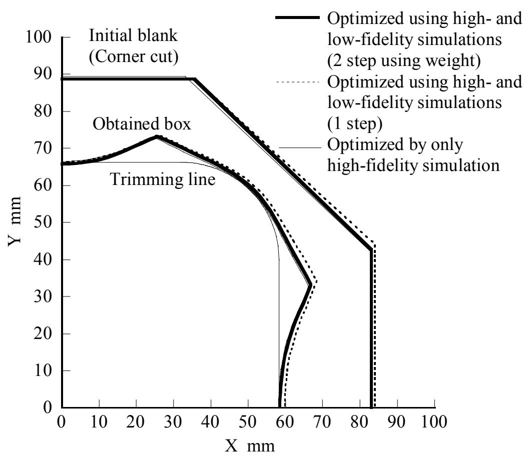

Figure 3. Optimum blank design and drawn box (corner-cut type)

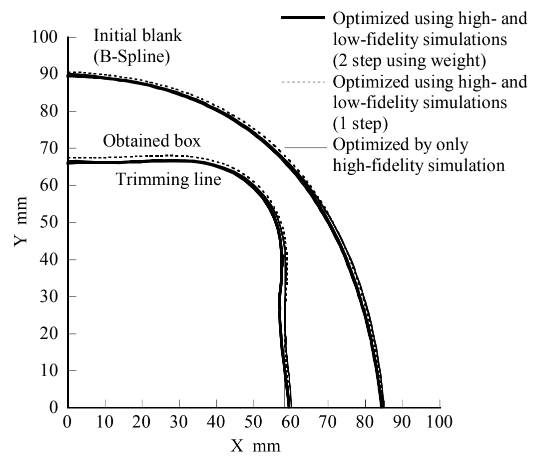

Figure 4. Optimum blank design and drawn box (B-Spline type)

Table 1. Results of optimization (corner-cut type)

	Optimized using high- and low-fidelity simulations (2 step, weighted)	Optimized using high- and low-fidelity simulations (1 step)	Optimized by only high-fidelity simulation
x_1	83.00	84.02	83.10
x_2	42.86	42.75	42.78
x_3	88.60	88.61	89.47
x_4	48.24	49.88	43.45
Objective	307.9	422.6	264.6
Time(min.)	113(22+26+65)	48(22+26)	1040

Table 2. Results of optimization (B-Spline type)

	Optimized using high- and low-fidelity simulations (2 step, weighted)	Optimized using high- and low-fidelity simulations (1 step)	Optimized by only high-fidelity simulation
x_1	84.44	84.65	84.93
x_2	89.54	90.58	90.27
x_3	87.90	90.11	91.48
x_4	98.72	97.91	94.44
Objective	12.0	83.4	29.3
Time(min.)	135(16+57+62)	73(16+57)	533