Equivalent Drawbead and its Application in Optimization of Autobody Forming Process

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ABSTRACT

In this paper, the effect of drawbead on autobody panel forming and the theory of equivalent drawbead are discussed. Compared with the effect of real drawbead, the feasibility and essentiality of equivalent drawbead model in process optimization and finite element analysis of sheet forming are pointed out. An example of car inner door panel is presented. By means of eta/DYNAFORM software, a LS-DYNA based sheet metal forming simulation package, defects of the current process are found, and an optimized process is given.

INTRODUCTION

With the competition of worldwide automobile industry, the forming of autobody becomes more important for the increasing requirements for appearance and feasibility. Due to the variety and complexity of autobody shape and its forming process, the traditional method of qualitative analysis and trial and error is not suitable for the development of modern industry. To improve product quality, shorten time to market and reduce development cost, many advance manufacturing technologies, such as computer aided engineering, concurrent design, virtual manufacturing, etc. are put forward. While numerical simulation technology, as a basic technology of concurrent design and virtual manufacturing, is getting more and more important in automobile industry.

With the development of numerical simulation technology of sheet metal forming, simulation precision of some forming defects, such as wrinkle, crackle and spring back, is improved greatly. Numerical simulation is playing a key role in process analysis and design of complex sheet metal parts.

At present, wrinkle or crackle is a main defect of metal forming, which always exists on unsymmetrical sheet metal parts because of their irregular forming. These defects are difficult to be avoided only by adjusting holder force or lubrication. So, the drawbead is widely used to overcome these forming defects in sheet metal forming process design. With the appropriate drawbead, forming condition can be improved and tends to be even, on the other hand, holder force can be reduced, then surface quality of product can be improved and life of tools can be extended.

Because the drawbead has an important influence on process optimization and the simulation of complex sheet metal forming, research on the drawbead is done thoroughly and many analytical models have been built by means of experiment and theory of plastic forming. However, these models are not accurate enough because there are too many influence factors, which can’t be included completely and many hypotheses are used in these models. In the research of the drawbead, numerical simulation technology becomes very important. By means of numerical simulation technology, calculation can be more convenient and the result is more precise.

It is difficult to simulate drawbead precisely especially in implicit-based program, because the size of drawbead is small and the complicated shape. To simulate the contact between blank and drawbead precisely, the fine mesh should be required, which will influence speed and precision of calculation badly. So, in numerical simulation technology of sheet metal forming, equivalent drawbead, instead of real drawbead, is often used.

APPROACH

Theory Model of Equivalent Drawbead

Equivalent drawbead can be regarded as a string of line on tools or molds, which is simplified from real drawbead, as shown in Figure 1. Its characters of geometry and mechanics are discussed below.

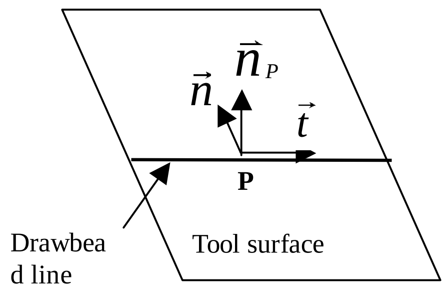

Figure 1. Drawbead Line on Tool Surface

1). The drawbead line sticks to mold surface on several nodes in mesh grid, the value of any point P on the line is determined by three orthonormal vectors: $\vec{t}$, $\vec{n}$ and $\vec{n}_P$. $\vec{n}_P$ is the normal vector of tool surface, $\vec{n}$ and $\vec{t}$ are the normal and tangent vectors to drawbead line in the plane which is tangent to tool surface at point P.

2). To point P, if u_i^b (i=1,2,3) is the displacement of blank opposite to tool surface, then the displacement of same position on drawbead line is u_i , $u_i = -u_i^b$.

3). Drawbead stress Q_i is the retaining drawbead force per unit drawbead length. (i=1,2,3)

4). According to the character of elastic-plastic materials, there may exist two states on the points of drawbead line, elastic and plastic, In elastic state, drawbead stress Q_i is less than marginal drawbead retain force, while the displacement between drawbead and blank is repeatable. In plastic state, drawbead stress Q_i is equal to or exceed marginal drawbead retain force, the displacement between drawbead and blank is not repeatable. So the displacement u_i of drawbead can be seperated to two parts, the elastic part u_i^e and the plastic part u_i^p , and the effect of drawbead line can be decided by a special constitutive relation.

5). Similar to orthogonal flow rule of elastic-plastic materials, u_i^p can be difined as:

$$u_i^p = \lambda \frac{\partial F}{\partial Q_i} \qquad (1\text{-}1)$$

where λ is a positive proportion coefficient. F= $f(Q_i) - Q_s$ =0

$f(Q_i)$ is the yield function of drawbead, $Q_s = Q_s(u_i^p)$ is the marginal drawbead retain force, which is determinded by the shape and size of drawbead.

6). The elastic part of drawbead is given by the consititutive relation below:

$$Q_i^e = E_{ij} u_i^e \qquad (1\text{-}2)$$

where E_{ij} is the modulus of drawbead.

Finally, the following equations are obtained:

$$Q_i = C_{ij} u_j \tag{1-3}$$

$$C_{ij} = E_{ij} - P_{ij} \tag{1-4}$$

$$P_{ij} = \frac{E_{il} \frac{\partial F}{\partial Q_l} \cdot \frac{\partial F}{\partial Q_m} E_{mj}}{4\vec{Q}_s^2 H^{'} + \frac{\partial F}{\partial Q_n} E_{nt} \frac{\partial F}{\partial Q_t}} \tag{1-5}$$

where C_{ij} is the constitutive tensor of drawbead, P_{ij} is the plastic part, $H^{'}$ is hardening or softening exponent. According to theory of elastic-plastic finite element method, equation (1-3), (1-4), (1-5) are similar to elastic-plastic constitutive equation.

DISCUSSION OF RESULTS

In this paper, an example of an inner car door is presented to investigate the reason of wrinkle and crackle and find an optimal forming process with current tools. DYNAFORM, a LS-DYNA-based and explicit dynamic based sheet metal forming simulation software, is used to simulate and optimize its forming process. Four major factor are considered: a) size and layout of drawbead, b) punch speed, c) holder force, and d) lubrication. Other factors are researched by experiment.

The finite element mesh of model with real drawbead is shown in Figure 2, which shows that at the area of real drawbead and the density of mesh is very high. This costs calculation time tremendously and also causes local abnormal result. Figure 3 shows the numerical simulation result of blank's thickness in current process. The area (blue color) pointed by arrows is the place with maximum thickness reduction, which is about 60% and there are crackles. This result checks with the situation of experiment and practices well with the product. However, the simulation process takes very long calculation time and it is just impossible to simulate many times for an optimation process. Then the equivalent drawbead is tried. Fortunately, its simulation result is consistent with the real drawbead. While calculation time is less than one quarter of the time taken by real drawbead. This means that equivalent drawbead is an effective way to substitute the real drawbead. So, the equivalent drawbead is used to optimize the forming process.

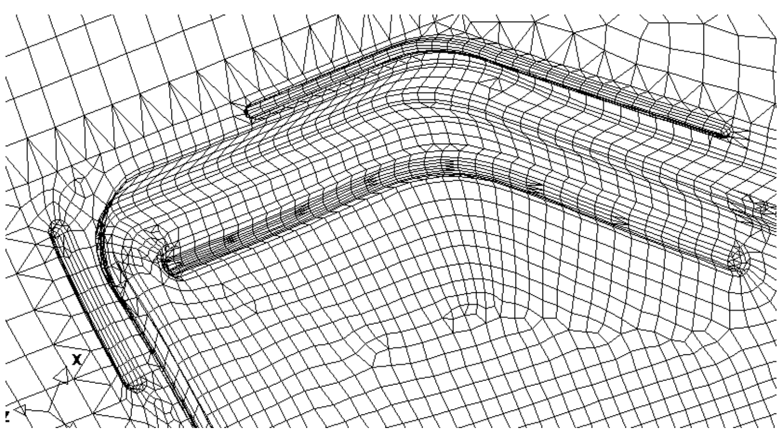

Figure 2. Finite Element Mesh of Real Drawbead

After several times calculation with different process factors, the drawbead can be regarded as the major factor which influences crackle and thickness reduction. Figure 4 shows the result at the same area with optimal shape and position of drawbead. The maximum thickness reduction is about 40% and there are no crackles .

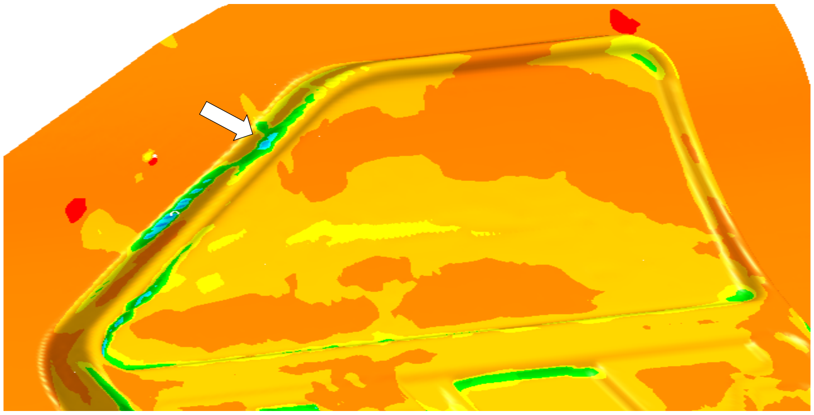

Figure 3. Thickness Distribution of Blank in Current Process

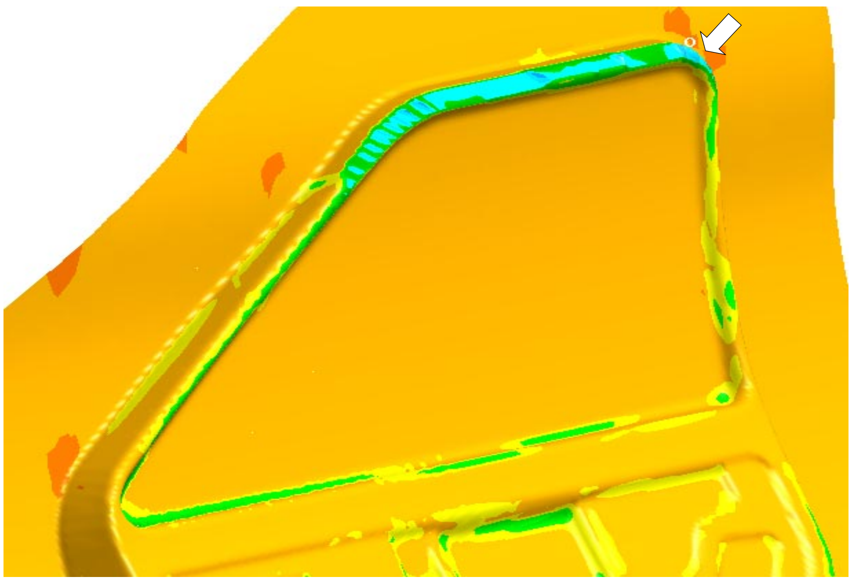

Figure 4. Thickness Distribution of Blank with Optimal Process

CONCLUSION

In this paper, the effect of the drawbead on the autobody panel forming and the theory of equivalent drawbead are discussed. An example of an inner car door is presented to investigate the reason of wrinkle and crackle and find the best forming process conditions. From this research, the following conclusions can be drawn: The drawbead can be regarded as one of major factor which influences the forming quality of complex sheet metal parts including wrinkle, crackle, thickness distrubition, etc. In numerical simulation, the equivalent drawbead can simulate the effect of real drawbead perfectly. It is a faster and effective method to use the equivalent drawbead in the optimization of sheet metal forming process.