5th Australasian Congress on Applied Mechanics, ACAM 2007
10-12 December 2007, Brisbane, Australia

Tool wear prediction on sheet metal forming die of automotive part based on numerical simulation method

Xuan Zhi WANG[1], S.H. Masood[1] and M. Dingle[2]

[1]Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, Victoria 3122, Australia
[2]School of Engineering and Technology, Deakin University, Waurn Ponds, Victoria 3217, Australia

Abstract: Tool wear is a main concern in the sheet metal forming of automobile parts due to the development and application of new materials and the high requirement of parts quality in automobile production. However, it is difficult and time-consuming to predict tool wear using a traditional method. This paper provides a rapid numerical simulation approach for predicting the tool wear on sheet metal forming die. The simulation was carried out using the finite element software AutoForm™. A tool wear model was presented as a foundation of the simulation. The recommended protection method for the die surface and the prediction of tool worn areas was obtained from the simulation. The predicted results were in accordance with the results obtained from the on-site production. The influences of the contact pressure and drawing depth on the tool worn area distribution were also investigated based on the simulation outcome.

Keywords: AutoForm software, finite element analysis, sheet metal forming, simulation, tool wear prediction.

1 Introduction

In automobile industries, sheet metal forming is widely implemented as an efficient deformation process to convert sheet metal into various interior and exterior parts with prescribed sizes and shapes. A rapidly changing automobile market demands high precision, perfect quality and a short lead time in the production of automobile parts. The tool wear of sheet metal forming dies is a major obstacle for industries to meet these demands due to the introduction of many new types of steel and complex three-dimensional shape of automobile parts.

Tool wear is a progressive damage to a die surface caused by relative motion with respect to a blank surface [1]. However, due to the complicated geometric, material and nonlinear contact nonlinear characteristics in the deformation of automotive parts, it is very time-consuming and costly to predict the tool worn area by means of try-out techniques based on conventional trial and error and engineers' experiences. To overcome the limitations of the traditional method, some research has focused on virtual simulation techniques to establish finite element models to predict the tool worn areas and their protection method [2–4]. In this paper, an efficient numerical simulation methodology to predict the tool worn location, using AutoForm™, is presented using a case study.

2 Finite Element Approach in AutoForm™

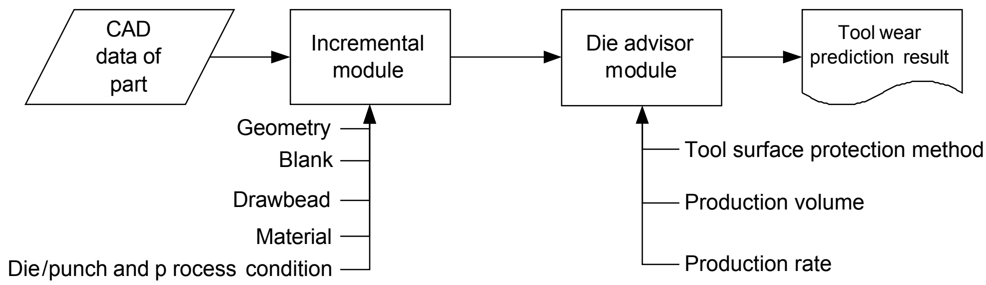

Figure 1 Simulation and optimization using AutoForm

In a sheet metal forming process, the tool wear is usually observed as a loss of tool material through adhesive wear by a number of junctions formed in the contact area [5]. The load applied on a die surface results in extremely high contact pressure in the contact area. As the tool surface adheres with the blank surface, the sliding friction between these two surfaces generates tiny wear particles. These high hardness particles then form the abrasive wear. The tool wear rate is affected by parameters including the tool material, blank material, material thickness, clearance between punch and die, punch velocity, lubrication, etc [6].

AutoForm™ software version 4.1 developed by AutoForm™ Engineering GmbH was employed to perform simulation of sheet metal forming and tool wear prediction, for which sequences of steps are illustrated in Figure 1. The tool wear model and its prediction algorithms in AutoForm™ software are based on a series of experiments implemented by the developers.

The AutoForm™ incremental module is used in the simulation of sheet metal forming by integrating geometry, blank, material and process generators. The modules provide accurate simulations for sheet metal forming based on the static implicit approach, which can be expressed as:

$$\int_{\mathrm{V}} T_{ij} \mathrm{d} u_{i,j} \mathrm{dV} = \int_{\mathrm{A}} t_i \mathrm{d} u_i \mathrm{dA} \tag{2}$$

where V is the volume, A is the surface area, T_{ij} is the Cauchy stress tensor, $u_{i,j}$ is the gradient of the displacements, t_i is the traction vector and δ is the variational operator [7].

The AutoForm™ die advisor module is used for the prediction of the tool wear location and the extent, and determination of the optimal surface protection of the tool. Various heat treatments such as furnace, laser, induction, flame and nitriding, and coating methods, such as vapour deposition (PVD), chemical vapour deposition (CVD) and hard chrome plating, together with protective coatings, including TiN, TiCN, TiAlN, hard-chrome and a-C:H, are supported by the module.

3 Case Study

3.1 Simulation model definition

Table 1 Material properties of reinforce rear suspension support

Young's module (MPa)	Poisson's ratio	Specific weight (Nm^{-3})	Strain hardening coefficient	Initial yield stress (MPa)	Strength coefficient (MPa)	Normal anisotropy
2.07×10^{5}	0.333	7.8×10^{-5}	0.13	420	766.25	1.0

Figure 2 Reinforced rear suspension support

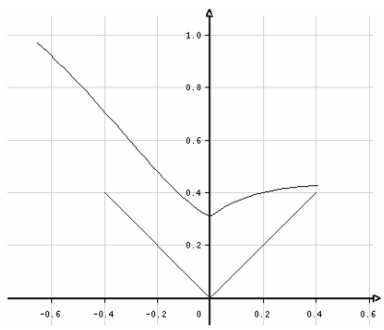

Figure 3 Forming limit curve

A reinforced rear suspension support of a vehicle was used as a case study (Figure 2). The material of the part is cold rolled hot dip galvanized high strength steel. Table 1 summaries the material properties of the part and Figure 3 illustrates the forming limit curve of the part obtained from an experiment. The production rate is 8 strokes per minute and production volume is 100,000. The thickness of the part is 2.5 mm, the friction coefficient between the tool and the part is 0.15, and the binder pressure is 4.5 MPa.

The geometry of the sheet metal part was meshed in AutoForm™ incremental module. The blank, blinder, punch and die were imported to the module by AutoForm™-UG interface, respectively, and placed at their specified locations according to the information obtained from the plant-site (Figure 4) .

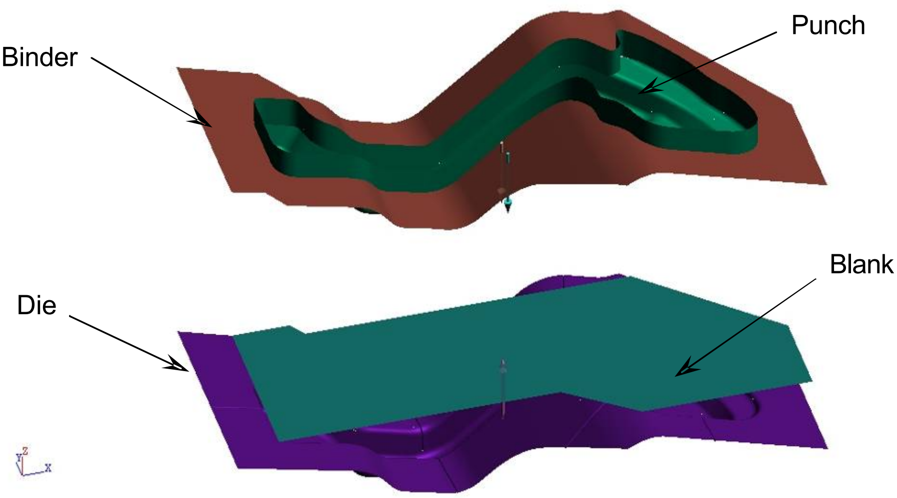

Figure 4 Blank, binder, punch and die

3.2 Results and Discussion

3.2.1 Recommended protections for tool surface

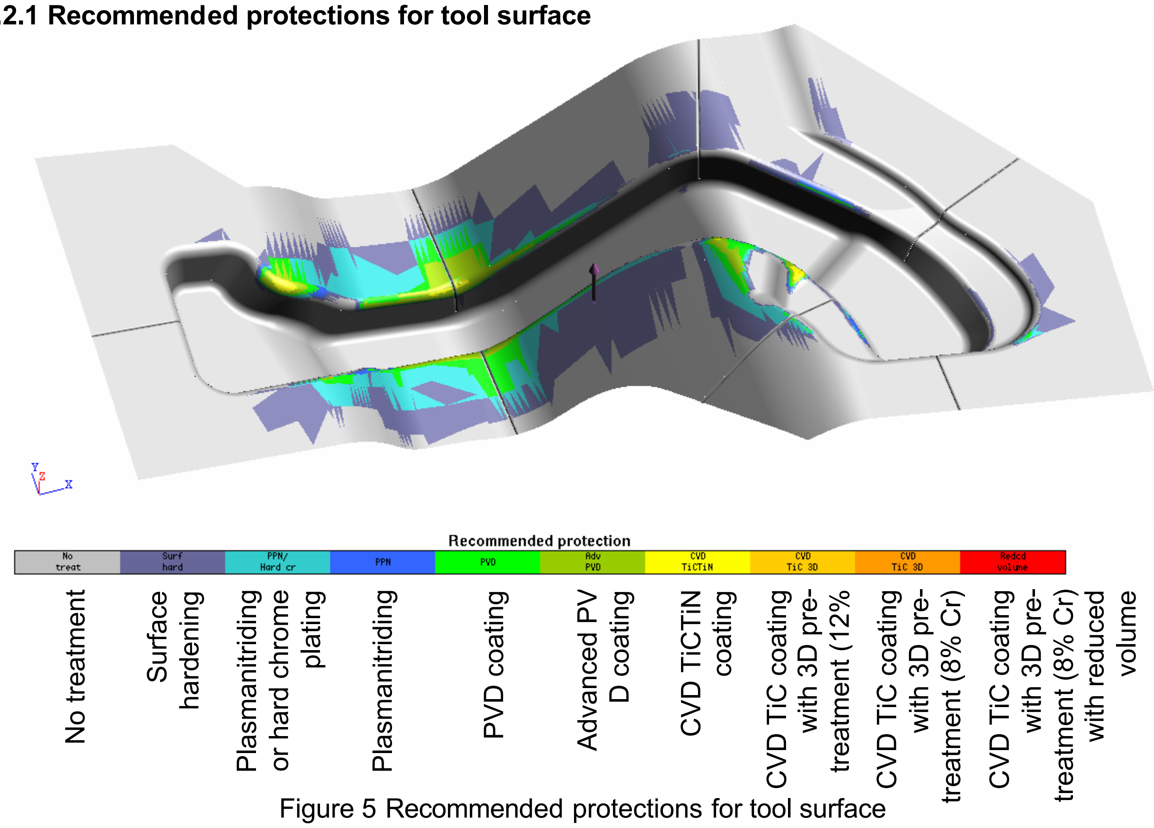

Figure 5 Recommended protections for tool surface

Figure 5 illustrates the recommended protections of the tool surface under the initial production conditions obtained from the simulation. For most of the die surface, there is no need to use a special protection method. For crucial worn areas in Figure 5, it is recommended to use CVD with TiCTiN coating. The tool wear

3.2.2 Comparison of predictive tool worn areas with on-site results

Figure 6 plots the tool worn areas distribution using CVD with TiCTiN coating. In Figure 6, the area with the colour close to yellow presents an area of sensitiveness to the tool wear, and the area with the colour close to green means an area of insensitiveness to the tool wear. From the results, it is concluded that Areas 1, 2, 3 and 4 are highly sensitive to the tool wear, and the tool wear would occur in the very early stage of the production.

Figure 7 illustrates the photos of the worn areas, named Areas 1', 2', 3' and 4', located on the surface of the sheet metal part, which contact to the corresponding Areas 1, 2, 3 and 4, respectively, in the sliding movement during the sheet metal forming process. The predicted result is found to be in accordance with the result obtained from the plant-site.

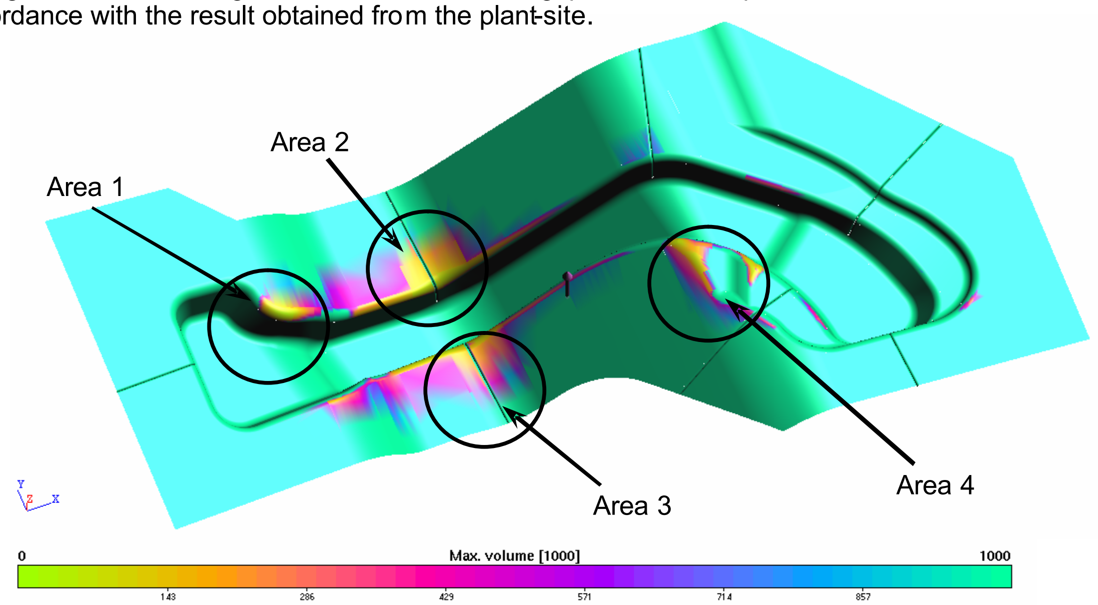

Figure 6 Tool worn area location using CVD with TiCTiN coating

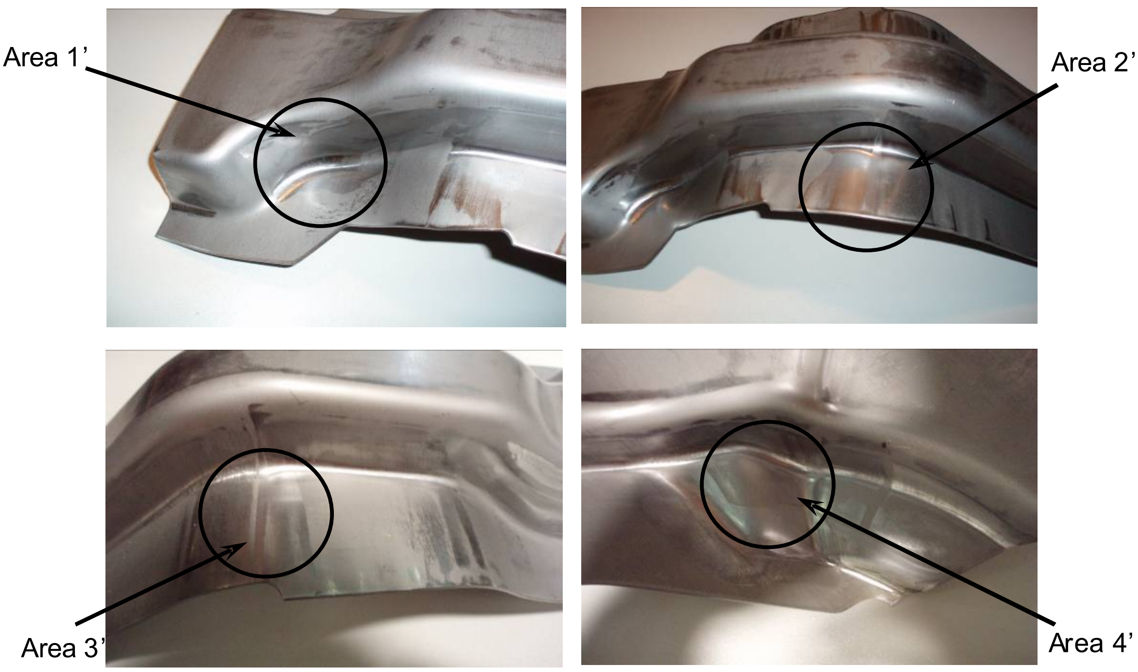

Figure 7 Photos of the worn areas on the corresponding surface of the sheet metal part

3.2.3 Relationship between tool worn area, contact pressure and drawing depth

To study the relationship between tool worn area, contact pressure and drawing depth, Areas 2 and 3 are selected as a sample. The worn area in the tool surface is corresponding to the surfaces of sheet metal part surface with high contact pressure. Figure 8 shows the contact pressure distribution and the drawing depth at the cross section on Areas 2' and 3' of the sheet metal part, which are the corresponding areas of Areas 2 and 3. The result shows the drawing depth changes rapidly in these areas. The gradient in these areas is extremely large in both longitudinal and latitudinal directions, which results in highly increased sliding movement between the tool surface and the part surface, and accelerates the formation of the worn area in both tool surface and sheet metal part surface.

From the simulation, it is concluded that the areas that are most sensitive to the tool wear occurs at the locations corresponding to the large gradient of drawing depth, and these locations are also the areas with high contact pressure.

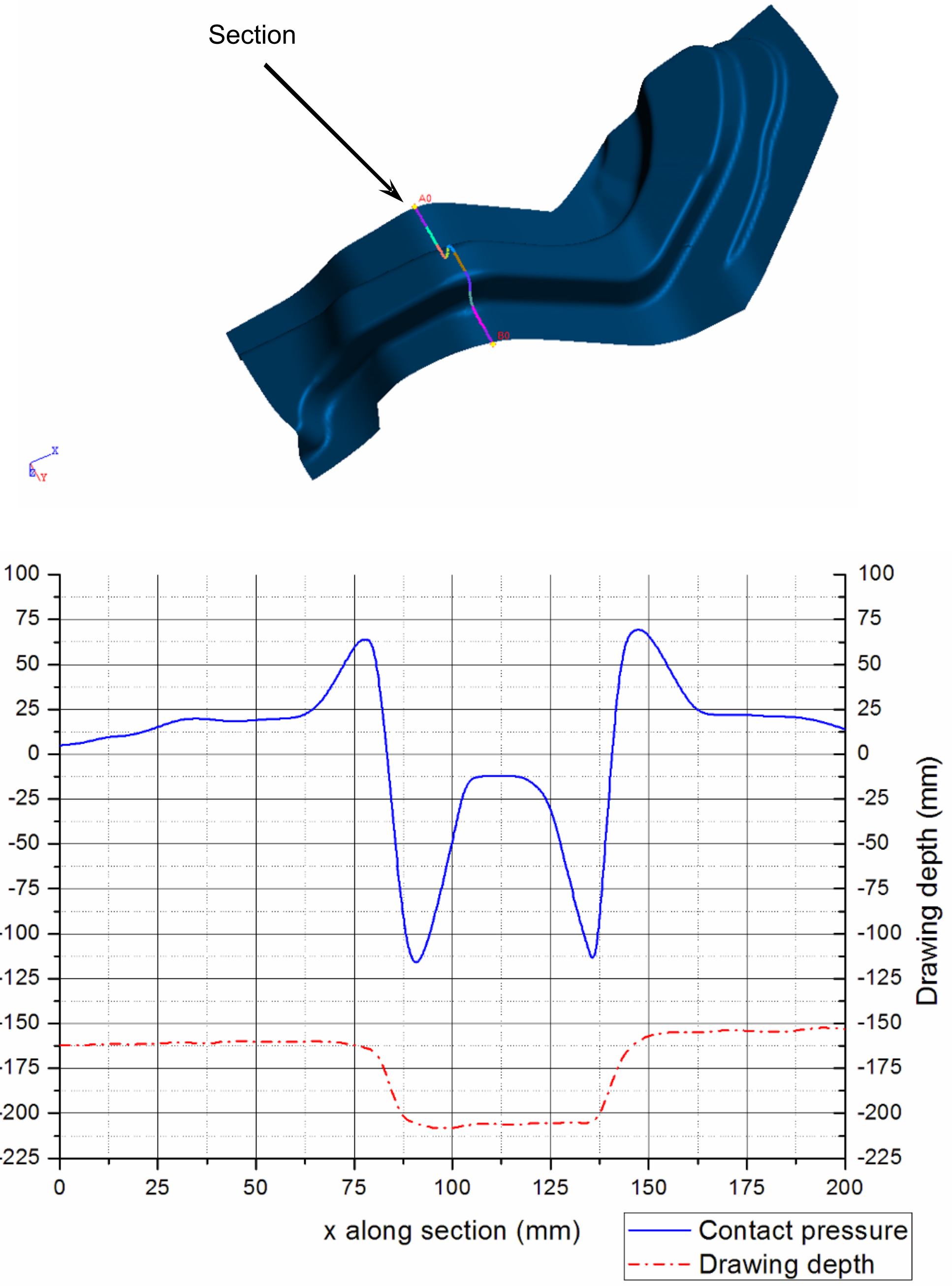

Figure 8 Contact pressure distribution and drawing depth at cross section

4 Conclusions and recommendations

The paper presents a rapid methodology for the simulation of sheet metal forming and prediction of tool wear location for an automobile part using finite element software AutoForm™. The recommended protection method was obtained from the simulation. The areas that were sensitive to the tool wear were also identified, which were in accordance with the phenomena observed from the on-site production. From the investigation of the simulation results, it was concluded that the tool worn areas are usually on the locations with a large gradient of drawing depth. The results in this study have shown a significant reduction of lead-time in the tool wear prediction for automobile manufacturer using numerical simulation method. Future work can focus on the identification of the influences of lubrication, binder pressure and material thickness on the tool wear distribution using AutoForm™ and other numerical simulation software.

Acknowledgement

The authors acknowledge the support provided by the Cooperative Research Centre for Advanced Automotive Technology (AutoCRC) in Australia.

References

[1] R.G. Bayer, Mechanical Wear Fundamentals and Testing (2nd Edition), Marcel Dekker, New York, 2004.

[2] O. Sandberg, P.-A. Bustad, B. Carlsson, M. Fallstrom and T. Johansson, "Characterization of tool wear in stamping of EHS and UHS steel sheets", Recent Advances in Manufacture & Use of Tools & Dies and Stamping of Sheet Steels, Olofstrom, Sweden, 5-6 Oct 2004.

[3] V. Hegadekatte, N. Huber and O. Kraft, "Modelling and simulation of wear in a pin on disc tribometer", Tribology Letters, 24(1), pp. 51-60, 2006.

[4] G.C.R. Moura, M.T.P. Aguilar, A.E.M. Pertence and P.R. Cetlin, "The material and the design of the die in a critical manufacturing step of an automotive shock absorber cap", Materials & Design, 28(3), pp. 962-968, 2007.

[5] S. Kalpakjian and S.R. Schmid, Manufacturing Processes for Engineering Materials (4th Edition), Prentice Hall, Upper Saddle River, 2003.

[6] R. Hambli, F. Guerin and B. Dumon, "Numerical evaluation of the tool wear influence on metal-punching processes", The International Journal of Advanced Manufacturing Technology, 21(7), pp. 483-493, 2003.

[7] M.L. Wenner, "State-of-the-art of mathematical modelling of sheet metal forming of automotive body panels", Sheet Metal Stamping: Development Applications, SP-1221, Society of Automotive Engineering (SAE), pp. 1-6, 1997,