Tribology in Aluminium Sheet Metal forming

M. PFESTORF
BMW AG München, Germany

1. INTRODUCTION

Since aluminium is not used solely for niche vehicles like the BMW Z8 but also for body in white parts in high volume vehicles like the bonnet of the BMW M3, the number of pressed aluminium panels has suddenly increased.
Originally, the number of aluminium parts produced in the press shop was very small compared to the output of steel parts. Hence the sentence 'aluminium as fast as steel' has become more and more important. Since this target cannot only be achieved by a design and construction especially for aluminium parts, there is a need to have a closer look at the forming operation itself and in particular the tribological system of the forming process. **Fig 2** shows the effect of the reduction of the friction coefficient to the forming limit line in the forming limit diagram.
The tribological system e.g. the friction coefficient is mainly influenced by lubrication, the texture of the blanks´ surface and by the surface or coating of tools. In the work presented here, 3D surface parameters for a better tribological description of the surface are shown as well as the results from dry film lubricants and the coating of tools.

2. 3D SURFACE PARAMETERS

In recent years a precise characterization of surface topography, especially in sheet metal forming, became more and more important. One of the reasons is the continously growing sophistication of the forming process facilitated not only by specific and closely controlled properties of the sheet, but by surface properties as well, given by the topography. Today quite different technologies for surface texturing are available yielding a broad diversity of topographies in practice e.g. the electro discharge texture (EDT) and the mill finish (MF) texture for aluminium sheets (**fig. 3**). **Fig. 4** shows the Peak count Pc and the arithmetic mean deviation Ra for EDT and for MF topographies. Looking at these 2d-values no difference can be made for topographies which are quiet different for tribological aspects. For that view, it is evident that the roughness characterization of technical surfaces based on a simple 2d description cannot be sufficient anymore.
With the rapid development of new measuring methods based on powerful computer techniques, the introduction of 3d surface parameters into research and industry is taking place [1]. A great advantage of these 3d surface parameters is the more precise description of the surface according to their industrial application [2]. For example - when looking at a 2d-measured profile, a pit is indistinguishable from a scratch. Both can be differentiated by 3d parameters. Additionally, some functional properties of the topography like the

tribological behavior in forming processes are almost impossible to describe using conventional 2d-parameters. In response to the great importance of friction in forming processes the development of new and more intelligent 3d surface parameters is thus essential.

New functional parameters can be derived from a mechanical rheological model which is about to be developed in order to understand and to describe the complex interaction between tool and billet (or sheet) taking place at the interface [3]. Within this model, the load on a surface is transmitted by three totally different kinds of bearing ratios. These are the solid contact area and the static and dynamic lubricant pockets. The ratio of solid contact corresponds to the relative amount of the real contact area. The dynamic lubricant pockets represent those regions of lubrication where during the forming process the lubricant can be squeezed out of the loaded area. In these regions the load can only be transmitted by hydrodynamic pressure. In contrast to the dynamic lubricant pockets, the static lubricant pockets have no connection to the boundary of the loaded area. Thus the lubricant is trapped in these pockets and a hydrostatic pressure can be built up. On real surfaces, the static lubricant pockets only occur at a certain flattening of the surface topography, which differs for each kind of surface. While normal stresses can be transmitted by all three kinds of contact mechanism, shear stresses can only be transmitted by solid contact. The proportion of the bearing ratios and their increase or decrease during a forming process depend on local parameters like normal stresses, sliding length and others. Considering these aspects, it is obvious that the amount of solid contact and indirectly also the other bearing ratios have a great influence on the coefficient of friction in the forming process. To characterize the topography following the idea of the model, three dimensional surface parameters have to be defined.

As shown in **fig. 5**, the relative amount of solid contact corresponds to the material area ratio. The 3d surface parameters for the static and dynamic lubricant pockets are the closed and the open void area ratio respectively. Referring to the model, the closed void area are those regions, which have no connection to the boundary of the evaluation area. In contrast, the open void areas are those regions which have a connection to the boundary of the evaluation area. The material area ratio has already been introduced by Stout [4] as a useful tool for the comparative analysis of surfaces. So, the decisive new idea of the parameters is the distinction between open and closed void areas. Similar parameters are also used in [5, 6, 7] for the characterization of the tribological properties of surfaces in forming processes.

For purpose of illustration **fig. 5** shows the results of a calculation of the surface parameters for a single crater from a laser-textured surface with separated lasertex craters. The material area ratio corresponds to the Abbott curve which is well known from 2d-surface analysis. The open and closed void area ratio also results as a function of the penetration of the surface. The area ratios are calculated within planes parallel to the mean plane. The first plane at a penetration of 0 % touches the highest asperity of the topography e.g. the last plane touches the deepest valley. On the first plane, at a penetration of 0%, only open void areas are present. With further penetration of the surface, the open void area ratio decreases as the material area ratio increases. In the third surface plot a section of the crater can clearly be seen. As there is no connection to the boundary of the evalation area, the crater is characterized by the closed void area. With further penetration, the open void areas disappear e.g. there are only closed void area ratio and material area ratio. At the end, 100 % material area ratio remains. At least, two significant surface parameters can be derived from this diagram. First of all, this is the maximum of the closed void area ratio α_{clm}. The other one is the closed void volume V_{cl} which can be calculated by integration of the closed void area curve. In this example, it is also obvious that the area ratios depend on the size of the measured area. It can be proved, that all three surface parameters are within very small variations at an evaluation area of 4 mm². The measured area is then 2,0 x 2,0 mm² with 266 x 257 measured points an a polynomial fit of the measured area. Based on a three-dimensional measurement of the surface, the surface parameters can be calculated using the SAM (surface analysis module) program which is described in [8].

Fig. 6 shows the closed void area ratio and the closed void volume for the topographies measured in **fig 4**. In contrast to the 2d surface parameters it is clearly to be seen that there is a clear difference between the EDT topographies and the Mill Finish topography. An other application is shown in **fig. 7** where the closed void volume was measured for two coils on the left, middle and right side as well as on the top and bottom of the coil. It was shown in a production process that coil 1 with a homogenuous topography shows good process conditions. Coil 2 with an inhomogenuous topography shows worse process conditions with splits on one side of the panel. Refering to these results a homogenuous topography of the blank is needed for a stable forming process. This can be proven by the mentioned 3d-surface parameters.

3. Dry Lubricants

Another important aspect in deep drawing of aluminium is the lubrication. Mostly conventional oiling is used in the press shop. But in the last few years the developmnent of several dry film lubricants came up. These dry film lubricants are applied by the aluminium supplier. First trials with dry lubricants were done with some parets of the BMW Z8. As it is shown in **fig. 9** the process of deep drawing of difficult parts is much shorter when dry lubricant can be used instead of conventional oiling. In these trials the dry film lubricant Drylube C1 from Zeller & Gmehlin was used. It is shown in **fig. 10** that the panel can be drawn with Drylube C1. Using the oil ALG 17 as well as the prelube KTLN16 (both Zeller & Gmehlin) splits occur in difficult areas.

Trials have been carried out with the bonnet outer of the BMW M3. The process is in the press shop shown in **fig 11**. Using a measurement equipment in the tool (**fig. 12**) [9] the forming energy for the Lubricant ALF 15 (Zeller & Gmehlin) and the two dry lubricants Alub ZX and Alub VS (both Alusuisse) was measured for a small serie of each. It is shown that the forming energy for both dry film lubricants is lower than the forming energy when using the oil ALF 15 (**fig 13**). From these results under series production conditions it can be stated that the friction in a forming process can be lowered when using dry lubricants.

4. Coating of tools

In some special applications, the use of a bonazinc coating on the panel may be a suitable way to prevent corrosion during the life time of a vehicle. One of these parts is the suspension cap shown in **fig. 15**. It is made from AlMg4,5Mn0,4 with a wall thickness of 3.5 mm and a draw depth of about 30 mm. As is shown on the drawing, it is a very complex part. Therefore, the first trials for series production produced only 250 parts using a hardened and ground steel draw die made of the steel 1.2379. The adhesion of the aluminium to the tool caused a reduction in panel quality and meant that a new grinding operation was necessary. The bonazinc coating however was hardly damaged. The draw tool was coated with WC/C which was applied in a PVD (physical vapour deposition) process with a thickness of 4 µm and a hardness of 3000 HV. With this coating, the lifetime of the tool was increased to more than 2.000.000 parts without any damage to the WC/C coating and gave an excellent panel quality.

5. WEAR PROTECTION PANEL

Even though, very good results were achieved with the WC/C coating, it is very expensive. In addition to this, the tool has to be hardened and damage of the coating by other parts may cause serious problems in production. Hence there is a demand to find another way to protect the tool against wear and surface damage by scratches and so on. Therefore the following describes how a totally new idea - the wear protection panel (WPP) - was tested (**fig. 16, fig 17**). The initial trials for the WPP in series production have been carried out by Vogel [10]. To use the WPP, the die (carrier) is milled out to accommodate the wear protection panel. This can be either the female tool, the punch, the blankholder or the whole tool. The blank for the wear protection panel is then deep drawn by using the carrier as a draw tool. For re-work, which may be necessary and also for polishing the surface of the panel, the WPP is simply removed from the carrier. For production, the WPP is fixed in the die by any suitable method. In order to reduce the cost of the tool, the carrier was made out of kirksite. For the trial, a difficult inner part made of AlMg4,5Mn0,4 coated with bonazinc 2000 was selected and the WPP was placed in the female die of the first deep draw operation. It must be mentioned, that the original tool for series production was again made out of WC/C coated steel. When using the WPP, 12.000 parts were produced under normal oiling conditions and at the same press output as the regular steel tool. At the end of the trial some defined radii were worn down as a result of the movement between WPP and blank. But this effect was only visible on the WPP and OK parts could have still been produced without any change to their pressed form. If the WPP is totally damaged, it can be easily replaced. The WPP is an easy and cost effective alternative to expensive tool coatings especially for low volume parts.

6. SUMMARY

It was shown that 3D surface parameters are able to describe the tribological properties of a surface much better than the common 2D surface parameters. In this article the parameters closed void volume V_{cl} and closed void area ratio α_{clm} have been used. It was also shown that the formability of blanks can be improved by using dry film lubricants. Dry film lubricants also shorten the manufacturing process in production for niche products as well as in mass production. To solve problems of adhesion of aluminium on the tools the WC/C coating was presented as a sufficient solution.

---

1 **Leonardo.P.J., Trumpold, H.; De Chiffre, H.:** Progress in 3D surface micro topography characterization. Ann. CIRP, 45(1996)2, pp. 589-598

2 **De Chiffre, L.; Cristiansen, S.; Scade, S.:** Advantages and industrial application of three Dimensional Surface Roughness Analysis, Ann. CIRP, 43(1994), pp.1 473-478

3 **Sobis, T.; Engel, U.; Geiger, M.:** A theoretical study of wear simulation in metal forming processes, J. Mater. Process. Technol., 34(1992), pp. 233-240

4 **Stout, K.J.; et al.:** The Development of Methods for the Characterisation of Roughness in three Dimensions, report EUR 15178 EN, EC Brussels, ISBN 0 7044 1313 2

5 **Schmoeckel, D.; Prier, M.; Staeves, J.:** Topography deformation of sheet metal during the forming process and its Influence on friction, Ann. CIRP, 46(1997), pp. 175-178

6 **Schmoeckel, D.; Staeves, J.:** Determination of the minimum quantity of lubricant for sheet metal forming, proceedings of the 1st. World Tribology Congress, 8-12 September 1997, London

7 . **Siegert, K.; Wagner, S.:** Three-dimensional sheet surface analysis, Production Engineering, 1(1993)1, pp. 53-56

8 **Pfestorf, M.:** Funktionale 3D-Oberflächenkenngrößen in der Umformtechnik. Aus der Reihe: Fertigungstechnik – Erlangen, Feldmann, K.; Geiger, M. (Hrsg.), Meisenbach, Bamberg 1997

9 **Girschewski, B.; Pfestorf, M.:** Einfluß von Trockenschmierstoff und Oberflächenstruktur auf das Umformverhalten von Aluminium-Blechen. Vortragstexte zur Konferenz *Neuere Entwicklungen in der Blechumformung* (Hrsg.: Siegert, K.), Fellbach, 23. –24. Mai. 2000, S. 437 – 456

10 **Vogel, D,; Hoffmann, H.; Hoogen, M.:** Formschalen für die Serienfertigung. Werkstatt und Betrieb, 132(1999)3, S. 81-83