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Image analysis of sheet metal surfaces

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The analysis of a sheet metal surface is essential to describe phenomena like friction or varnishing ability. As 2D measurements are not sufficient for a full understanding of the surface performance, 3D image analysis methods are performed to characterise the topography of rough surfaces. In this paper some investigations are presented concerning the lubrication area and the material cut spots of a St14 sheet surface. To consider relevant aspects for metal forming, roughness measurements have been performed with elongated and loaded sheets. The evolution of the surface structure is essential to understand effects like the lubricated friction or the contact between the paint and rough surfaces.

1. Introduction

Friction is a very important influence factor in metal forming. Especially regarding sheet metal forming the surface of the workpiece has to be considered more precisely in order to build up an adequate model for the numerical simulation of the whole forming process. One of the most important parameters influencing the frictional behaviour is the real contact area between surfaces, i.e. workpiece and tool. A great number of investigations has been done to model the contact area of rough surfaces [1–3]. The structure of engineering surfaces is complex and 2D measurements are not always sufficient for a full understanding of the phenomena occurring in the surface layer. 3D analysis enhances the description of the topography of rough surfaces. These 3D measurements can be used to visualise the surface and to create various maps, e.g. images, contour plots and numerical cuts.

In this study 3D data of sheet metal surfaces are converted into an image. Subsequently an image analysis has been performed to assess surface characteristics like height distribution, asperity distribution, or lubrication areas. This has been compared to conventional 2D parameters. The result shows the insufficiency of 2D analysis regarding a better understanding of the surface structure.

2. Roughness measurement

The sheet metal analysed in this work is a St14 steel. 2D and 3D surface measurements are performed using a Perthometer S8P with a laser optical stylus apparatus focodyn (Mahr GmbH, Göttingen). The 3D surface data correspond to a spatial (x, y, z) matrix where x and y are the longitudinal respectively the transversal position of a point, and z is the height at this point. Using the VISILOG programme [4], the 3D data were converted into an image formed by a grid of pixels [5]. To define the roughness characteristics the image was cut numerically. As the structure of asperities is very important to understand such phenomena like lubrication, friction and varnishing ability, it was of interest to study the evolution of the cut spots and of the lubrication areas with the height of the cut. Fig. 1 shows a cross section of the measured surface at the main plane. The white colour corresponds to the cut spots.

3. Results

3.1. Cut spot statistics

Varying the height of the numerical cut, the area spots have been measured individually and their number and total area have been defined. Fig. 2 presents the total area of spots and the height distribution of the surface obtained from a 2D profile. One can observe that the 2D height and the cut spots follow a Gaussian distribution, but their courses are distinct. This is due to the fact that the 3D spots correspond to the 2D summit height which differs from the surface height. The distinction between the mean plane and the summit height is important for lubricated friction [6]. The Abbot curve which is calculated from profiles is usually used to characterise surfaces and has no equivalent in 3D roughness. On the other hand the relative area of cut spots is a more appropriate parameter to be compared to the Abbot curve. Fig. 2 reveals that although they are different, their variation behaviours are similar. Their value at the mean plan is equal to 0.5, which is a characteristic of a random Gaussian surface.

3.2. Cut spots and lubrication area characteristics

The VISILOG program permits to measure the surface of cut spots and lubrication area individually. In this work, the lubrication area is defined as the area, not

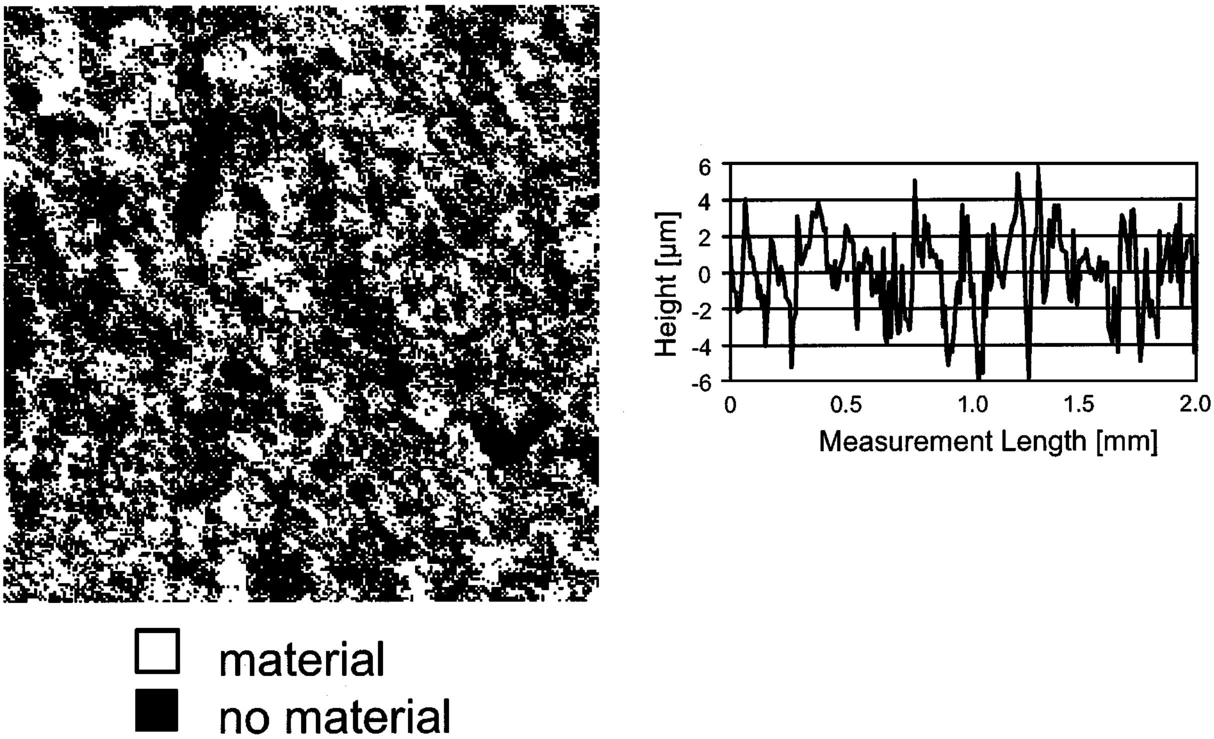

Figure 1 Cross section of a 2×2 mm^2 surface area part at the main plane level (0 μm height).

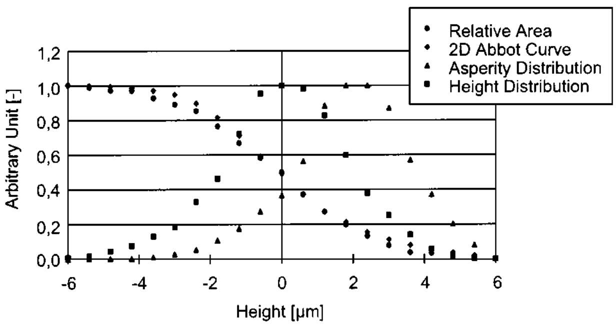

Figure 2 2D and 3D statistics obtained from image analysis.

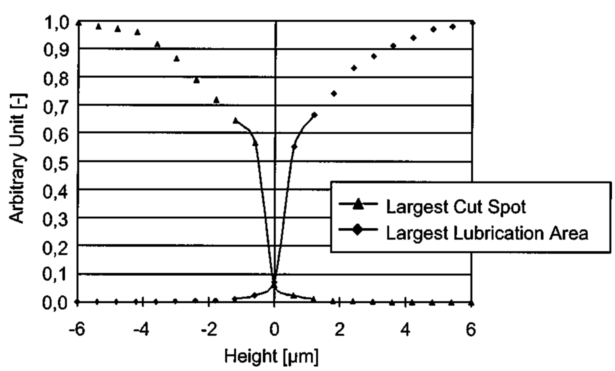

Figure 3 Evolution of the largest cut spot and lubrication area.

filled with material. These two parts are formed by an accumulation of islands. An additional point of interest is to study the evolution of the largest island area with the height of the cut level. The evolution of these two parameters is presented in Fig. 3.

One can observe that the two parameters are rigorously symmetric regarding the main plane level. Starting from the lowest height, the lubrication area reaches a minimum and increases slowly towards the main plane. In this zone, suddenly the variation gets a strong gradient until it follows a more weak slope. This kind of behaviour was observed for many other physical phenomena and can be explained by the Percolation Theory. It is analogous to cluster growth on surfaces [7] and can be illustrated as follows: Beginning with the lowest height, the lubrication area is formed by small independent islands. Their areas increase slowly and independently up to the mean plane. There, a great number of them agglomerate (collapse) and become one entity. This phenomenon can be well observed regarding Fig. 4. The white colour corresponds again to the cut spots. In order to recognise the percolation phenomenon more clearly, the lubrication areas are marked with blue colour. It is to be found that at the mean plane they are distinct and form different entities (The blue area is used for guidance). Their total area calculated by image analyses is equal to 0.5. In the right picture, which is from the cut at the height of 0.5 μm, the islands agglomerate and they are not more independent, but form one large area (blue colour). There is no possibility to determine the evolution of the lubrication area and the asperity area from conventional 2D measurements. Thus, the only way to obtain a better comprehension of the surface structure is to analyse 3D roughness data.

This phenomenon is undoubtedly very important for sheet metal forming especially for lubricated friction and varnishing ability. For a height less than the mean plane the lubricant or the painting liquid is imprisoned in independent holes and can not move from one to another. This observation is essential to understand the lubricated friction and the contact between paint and rough surfaces. Sheet metal surfaces used in industry are mostly conditioned by deep drawing which means bending, stretching and press deformation. To confirm

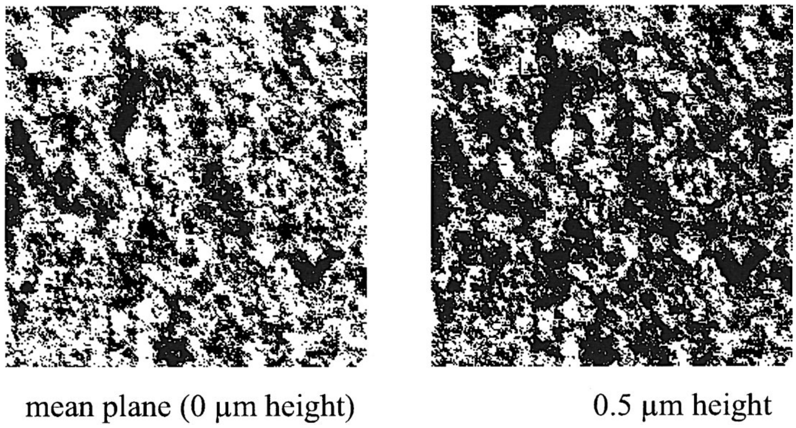

Figure 4 Growth of lubrication areas.

the percolation behaviour, a St14 sheet metal has been treated with plastic strain and compressive load.

3.3. Analysis of plastic elongation and loaded surfaces

The above mentioned sheet metal has been elongated quasi-statically with a plastic elongation of 20 and 30% respectively. Afterwards the variation of the largest lubrication area and the spot area are measured. Fig. 5 presents the 2D height distribution for the initial structure and the elongated sheets. One can see that the height distributions are different but still follow a Gaussian behaviour.

The evolution of the lubricant areas shown in Fig. 6 presents a leap of the largest area around the mean plane for all three sheet samples. This result indicates that for random Gaussian surfaces the evolution of the lubrication areas and spot cuts has a percolation behaviour. To confirm this characteristic, a comparison with non-Gaussian surfaces is necessary. Subsequently, different loads are applied to the surface, and the same parameters are studied.

In Fig. 7 the height distributions of St14 are presented after different applied loads. A comparison with the non treated sheet reveals clearly that the surface changes depend on the intensity of the contact pressure. It is to be observed that the height distribution is non-Gaussian and its maximum does not correspond to the mean plane but varies with the load.

The results of the measured greatest lubrication areas are presented in Fig. 8. Its values for the sheet without applied load show a leap around the mean plane. For all treated sheets the areas around the mean plane increase with the load, too. Their variations with the height however increase more slowly and present no leap around the mean plane. This means that they follow no percolation behaviour.

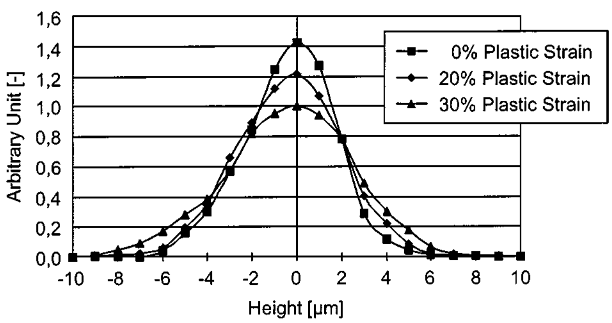

Figure 5 Height distributions for 0, 20 and 30% plastic strain.

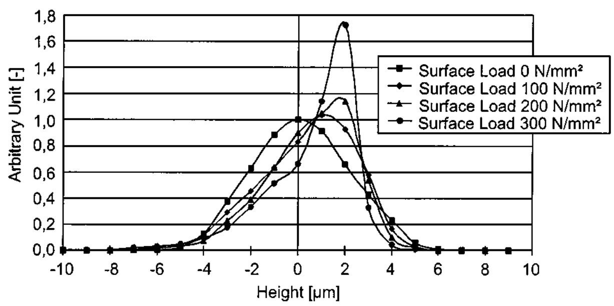

Figure 7 Height distributions of St14 after different applied loads.

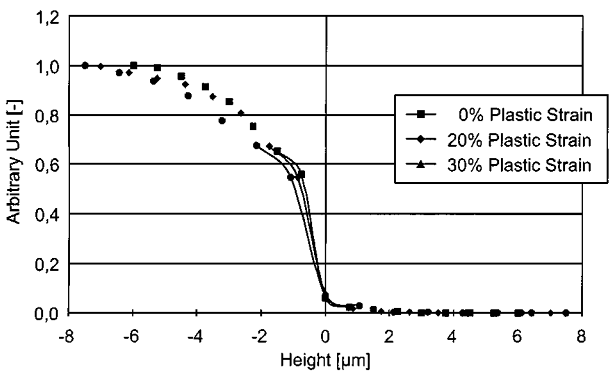

Figure 6 Comparison of the evolution of the largest cut spot area.

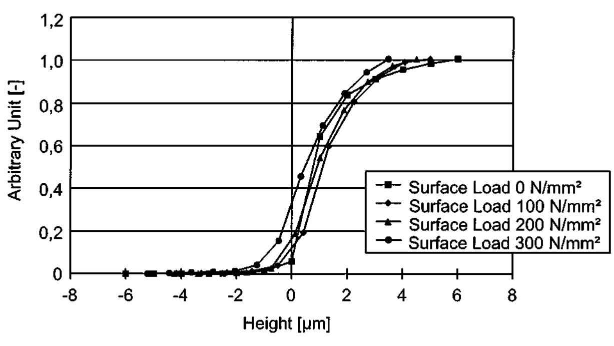

Figure 8 Comparison of the evolution of the largest lubrication area.

The measurements for elongated and loaded surfaces show that the structure of lubrication area and cut spots is related to the height distribution. It is evident that the flow of lubricant and its contact with the material depends on the structure of roughness. This structure is changed by the applied load. Therefore, the structure of the lubrication area and cut spots varies with the load, too. These observations play an essential role for the complex phenomenon friction and have to be taken into account to understand and to model tribological effects. Additionally, the evolution of the surface topography under applied loads and plastic elongation becomes important for the varnishing ability of a practical deep drawing part, e.g. an automotive sheet. The contact between the painting and the sheet metal depends on the roughness. The fact whether a surface has a percolation behaviour or not is surely important for adhesion and drying of the painting and has to be considered for industrial application.

4. Conclusion

2D roughness measurements reveal for Gaussian St14 steel sheets no effect on the height distribution due to plastic elongation. This study uses image analysis which was gained from 3D measurements. Their evaluation indicates that for these types of surfaces the evolution of lubrication area and cut spots follow the percolation theory. This behaviour is indubitable very important for a better understanding and modelling of sheet metal surface topography. In the opposite, loaded surfaces are not Gaussian any more. Thus, they show no percolation characteristics. However, the exact description and characterisation of loaded surfaces is a key for the understanding of friction phenomena as the formation of the contact zone between tool and workpiece is built by the contact pressure.

For this kind of analysis 3D roughness measurements are absolutely necessary in order to characterise the lubrication area (free, i.e., no-material area) which is a fundamental parameter in tribology. From 2D measurements one can only get parameters like height distribution, peak number or the Abbot curve.

The observations concerning St14 surfaces do not allow a generalisation of the statement that a free Gaussian surface always has a percolation behaviour. Further investigations have to be performed on this topic.

The industrial relevance of this study consists of the fact that during the forming process of sheet metal parts, free and loaded roughness regions are generated simultaneously. Thus, the prediction and quality determination of the whole surface topography with innovative models has an enormous practical meaning. The optical impression of a sheet metal part which depends on these regions is e.g. an important quality criterion in the automotive industry. Further research has to focus on a relation between the percolation theory and tribological or optical effects.

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