Basics for inline measurement of tribological conditions in series production of car body parts

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Abstract. The quality of car body parts in series production is strongly dependent on the tribological behavior. Fluctuating material properties such as the sheet roughness and the amount of lubricant have an influence on the forming process. On the basis of large amounts of data it is possible to investigate the friction behavior in series production and to make process adjustments if required. Therefore, inline measurement systems have a great potential to detect the sheet roughness during the cutting process of blanks in the coil line. Furthermore, contactless systems are advantageous as they do not damage the surface. Nevertheless, the optical measuring is influenced by the lubricant layer on top of the surface. Therefore, the previously unknown impact of the lubricant on the measuring result is investigated.

Within this study, stationary optical roughness measurements have been conducted using different amounts of lubricant on hot-dip galvanized EDT steel. The results demonstrate the influence of different amounts of lubricant on the sheet roughness measurement. Hence, it is possible to correct the inline measuring results and gain knowledge of fluctuating surface roughness. In addition, strip drawing test has been carried out to investigate the effect of fluctuating tribological conditions.

1. Introduction and state of the art
The manufacturing of car body parts regarding the forming process is influenced by several factors. These include for example the settings of the press line and the forming tool as well as the characteristics of the material. The material properties of the coils are often subject to fluctuations [1] which have an effect on the forming result and are therefore reflected in the part quality. Besides fluctuations of the sheet thickness and the mechanical properties, the amount and the distribution of lubricant [2] as well as the sheet roughness play a key role regarding the tribological conditions in the production of car body parts. These batch fluctuations are still under investigation, which is a reason why the process is continued to be manually adapted when problems occur.

Nowadays, it is possible to analyze batch fluctuations by means of large amount of data. Purr et al. present a new method for continuous inline detection of material properties in the coil line and show the characteristic of several batches of material [3]. The acquisition of material properties using inline measuring systems enables the investigation of fluctuations of the surface roughness as well as the
amount and distribution of lubricant and hence the impact of the tribological behavior in series production of car body parts. For this purpose, appropriate measurement technology is required.

For measuring the surface roughness two conventional methods are state of the art in the laboratory environment; the tactile and the optical roughness measurement [4]. Both of these methods could be applied in the production environment, but have their advantages and disadvantages. The roughness measurement by use of a tactile stylus measuring instrument is the most common method for measuring the surface roughness. One disadvantage of this method as an inline measuring system would be that the coil line has to be stopped to conduct the measuring. In addition, the stylus might cause scratches [5] on the surface which could be visible on the final car body part. These difficulties do not occur by usage of optical methods for surface roughness measurement. However, the lubricant layer used i.a. as corrosion inhibitor on top of the surface can influence the roughness measurement.

Using optical, laser-based methods, the laser beam first passes through the lubricant layer before hitting the base material. As a consequence, the measurement result could be falsified by the reflection of the laser beam on the lubricant surface. Nevertheless, this method offers the potential to identify the characteristics of surfaces, allowing conclusions to be drawn on batch fluctuations and thus on the tribological conditions.

In this paper investigations of inline measurements of the sheet roughness of coils and the influence of the amount of lubricant on the measuring value are described. In addition the effect of different tribological conditions of several batches is investigated by a strip drawing test. The overall aim of this study is to develop an evaluation method for the determination of tribological conditions by inline measuring systems.

2. Approach

In order to determine the tribological conditions in series production of car body parts the influence of the lubricated sheet surface on the sheet roughness measuring is analyzed. The findings can then be applied to the inline roughness measurement, for a surface characterization. The determined tribological conditions are then analyzed in a strip drawing test. Figure 1 shows the procedure for the investigations.

![Figure 1. Procedure for the investigations.](image)

The following investigations and results show a possibility to gain information about batch fluctuations regarding the sheet roughness and the amount of lubricant by inline measuring systems. Hence, the impact of batch fluctuations and the effect on the tribological behavior in series production of car body parts can be investigated and assessed. In addition, the findings can be utilized to develop an understanding of the process, regarding the tribological behavior.

3. Influence of the amount of lubricant on the roughness measurement

The following section describes the experimental investigations carried out to determine the influence of the lubricant on the roughness measurement. In addition, the results are discussed and a factor for the correction of the measured roughness values is derived.

3.1. Experimental investigations

Since it is assumed that the lubricant falsifies the roughness measurement depending on the amount of lubricant, stationary tests were carried out in order to determine the influence of the lubricant amount. For this purpose, several samples of a hot-dip galvanized CR3 steel with an electro discharge texturing (EDT) has been taken from different coils. Subsequently, the samples have been analyzed under stationary conditions. Therefore, the samples were cleaned in an ultrasonic bath in order to remove
residues of lubricant and dirt. In a second step, the maximum desired lubricant quantity of 3.0 g/m² was applied. Following, the lubricant has then been removed step by step between each measurement. The measurements of the sheet roughness and the amount of lubricant were carried out using the same systems as those implemented in the coil line. In addition, reference measurements were carried out using a tactile stylus measuring system. The results gained from the stationary investigations could hence be used for the correction of the sheet roughness measurement values in the coil line, as the amount of lubricant is also known.

3.2. Results
In order to determine the expected influence of the lubricant on the optical inline measurement of the sheet roughness measuring value, stationary measurements of the sheet roughness and the amount of lubricant has been performed as explained beforehand. For the investigations the arithmetic average roughness Rₐ is used, as it is the common parameter for characterizing sheet surfaces [6]. Figure 2 shows the comparison of the lubricant free surface roughness measurements using the optical laser-based system and a tactile stylus measuring system on four different samples. The measurements show a good accordance of the roughness values determined by the different measuring systems. The deviations can be caused by the fact that it is difficult to perform the measurements at exactly the same measuring point. Thus, it is proven, that the laser-based system is appropriate to determine the sheet roughness under lubricant-free conditions. Therefore, the influence of the lubricant quantity can be analyzed, as described in the following.

Figure 2. Comparison of the measurement results recorded by means of the tactile stylus measuring system and the laser-based measuring system.

The typical range for the lubricant quantity in series production is between 0.5 g/m² and 2.5 g/m². In order to investigate the influence of the amount of lubricant a range between 0.0 g/m² and 3.7 g/m² was selected, to cover fluctuations of the lubricant quantity. In figure 3(a) the measured roughness values are applied as a function of the lubricant quantity, which has been determined by the laser-based measuring system. The trend line illustrates the assumption that the roughness measuring value decreases with increasing amount of lubricant, up to a lubricant quantity of 2.5 g/m².

The increase in the values for higher lubricant quantities results from the fact that the reflection and scattering signals of the lubricant and the base material can be clearly separated from each other after a small transition range.

In order to compensate the falsification of the roughness measurement values caused by the lubricant a correction factor is required.
On the basis of this data a formula can be determined to correct the falsified roughness measuring values. For this purpose, the difference between the roughness values falsified by the lubricant $R_{a,lub}$ and the roughness value $R_{a,true}$ measured under lubricant-free conditions has been build. Afterwards, the differences of the measured roughness values has been plotted as a function of the lubricant quantity (figure 3 (b)). Thus, a correction factor was built based on this data (1), with which the measured roughness values, falsified by the lubricant layer, can be corrected (2). Therefore the information about the lubricant quantity $d_L$ is required. Hence, this formula can be applied on further inline measurements to correct the falsification.

\[
\frac{R_{a,true}}{R_{a,lub}} = C = -0.036 \times d_L^2 + 0.1599 \times d_L + 0.9838
\]  

(1)

\[
R_{a,true} = C \times R_{a,lub}
\]  

(2)

4. Determination of the roughness in series production and correction of measurement values

In order to investigate the occurrence of material fluctuations with regard to the sheet roughness as well as the amount and distribution of lubricant the method used for inline data acquisition in press plants, is described. Inline measuring systems offer the potential to determine the material properties of the delivered coils in the press plant. Therefore, several measuring systems are implemented in the coil line before the cutting process of the blanks. In addition, a new system was integrated to determine the surface roughness in the coil line. The recorded data are assigned to a laser code that is applied onto the blanks and are stored in a data base. Hence, these data can be utilized for investigations of the tribological behavior. Detailed information about this method can be found in [3].

Besides the magnetic residual field strength as an indicator for the mechanical properties, the sheet thickness, the amount of lubricant and the sheet roughness are recorded in the coil line. The sheet roughness is determined at five positions across the coil width on both sides of the sheet surface. Whereas the amount of lubricant is determined at twenty positions across the coil width on both sides of the sheet surface. Thus, it is possible to gather information of batch fluctuations along the entire coil. The data collected in this way can then be used to investigate the tribological behavior in series production.

4.1. Results of inline measuring of tribological conditions

Since fluctuating material properties have an influence on the tribological conditions, different batches of the inner door panel of the current BMW 3 sedan have been chosen to investigate these effect. The inner door panel is a structural component with a lubricant specification of $1.0 \pm 0.50 \text{ g/m}^2$ prelube and a roughness specification $R_a$ of 1.30 $\mu$m to 1.80 $\mu$m.
Based on the beforehand performed investigations it is now possible to enhance the inline measured sheet roughness values by a correction factor. In order to correct the inline measured sheet roughness values the data from the amount of lubricant, also determined in the coil line by an inline measuring system is used. As the sheet roughness is detected at five tracks over the coil width, the values of the lubricant quantity is needed at these five positions. Afterwards the inline measured roughness values $R_{a,lub}$ can be corrected to $R_{a,true}$. Figure 4 illustrates exemplarily the sheet roughness values $R_{a,lub}$ and the corrected sheet roughness values $R_{a,true}$ of one batch for one measuring track. The figure shows that the corrected roughness values are approximately 8 % higher than the measured roughness values, which was to be expected as the roughness measurement values are reduced by the lubricant film. Furthermore, it can be seen that over the length of the coil, measured on one track, only slight fluctuations in roughness occur. This was to be anticipated, as the skin pass rolls pass the surface continuously. The outliers in the corrected roughness values are caused by the fact that the lubricant values at these positions are zero. However, it can be assumed that these are measurement errors, as no lubricant-free areas are to be expected.

In figure 5 the lubricant amount as well as the measured roughness values $R_{a,lub}$ and the corrected roughness values $R_{a,true}$ are presented as a mean value over the respective measuring tracks. The distribution of the lubricant quantity over the coil width shows a typical appearance. Due to the transport and storage of the coils, a redistribution of lubricant occurs as the lubricant squeeze out in the edge area. Thus, the lubricant quantity $d_L$ at track 1, track 4 and track 5 amounts more than 1.35 g/m² lubricant. Whereas, at the inner area of the coil (track 2 and track 3) the lubricant quantity $d_L$ amounts 0.75 g/m² respectively 1.06 g/m². The exact allocation of the lubricant quantity per track is necessary for the correction of the roughness values. The inline-measured and enhanced roughness values show a similar behavior as the example for recording the measured values for a track over the coil length (figure 4). Due to the correction of the inline measured roughness values the corrected value lies between 8 % and 14 % higher than the actual measured value. Moreover, fluctuations across the coil width can be seen. In the edge areas the roughness is slightly lower than in the middle of the coil. This effect might occur due to the crowning of the sheet or the skin pass rolls, during the rolling process.

On the basis of these results it is now possible to characterize the batches using its surface properties, including the amount of lubricant and the sheet roughness values. Thus the tribological conditions of the batches can be investigated.
5. Investigation of the tribological conditions in a strip drawing test

5.1. Strip drawing test

In order to investigate the tribological behavior of different batches of one material three batches of a CR3 hot-dip galvanized EDT steel have been chosen to perform strip drawing tests. To reproduce the tribological conditions present in press plants, blanks from three different coils as delivered has been used to cut out samples. These have been removed from blanks of the inner door panel of the current BMW 3 sedan. Figure 6 illustrates the positions of the removal of the strips as well as the measuring positions of the sheet roughness measurement. The strip geometry is 110 mm x 700 mm. In addition, the material GGG70L has been selected for the friction jaws, as it is utilized for forming tools in series production [7]. The dimension of the friction jaws is 80 mm x 150 mm. Figure 7 shows a schematic set up of the strip drawing test as well as the parameters and the evaluation area for the determination of the friction coefficient. Since experiences has shown that the lubricant quantity scatters more than the roughness, an additional lubricant quantity measurement is carried out on the top and bottom side of each strip at three positions.

![Figure 5. Mean values of lubricant amount, inline-measured sheet roughness and corrected roughness values for each measuring track.](image)

![Figure 6. Strip position at the inner door blank and inline measuring positions of material properties.](image)
5.2. Results of the strip drawing test

To illustrate the characteristics of the three batches, the roughness values and the lubricant values which have been assigned to the strips are averaged for each batch. Figure 8 (a) shows the roughness values of the three batches. The roughness values in total do not show any major variation and lie in a small range between 1.83 µm and 2.08 µm. Nevertheless the roughness values differ for each batch. Figure 8 (b) shows the lubricant quantity per batch, determined using the additional manual lubricant quantity measurement. On the other hand the values for the lubricant quantity, show notable differences. Batch 1 and batch 2 reveal comparably high lubricant quantities of 1.09 g/m² and respectively 1.20 g/m². Whereas the amount of lubricant of batch 3 amounts 0.66 g/m². These differences with regard to the material properties are reflected in the determined coefficients of friction.

In order to illustrate the effect of the different tribological conditions, the ratio between the roughness and the amount of lubricant has been built, since a combination of these two factors influences the friction behavior. Figure 9 shows the comparison of the ratio between the roughness and the amount of lubricant to the friction coefficient. It can be seen that each batch has its own characteristic regarding the tribological behavior. Batch 1 and batch 2 are characterized by a relatively high lubricant quantity and show low friction behavior.

The roughness to lubricant ratios are in the range between 1.23 and 1.99 with the exception of a few points. The coefficients of friction are between 0.086 and 0.101. In comparison, batch 3 shows higher roughness values as well as a lower amount of lubricant, which suits to the results of higher friction. With a few exceptions, the ratio of roughness to lubricant for batch 3 is above 2.91 and shows friction coefficients above 0.102. However, there is an area in which the tribological conditions of the different batches overlap. In addition, however, the investigations have shown that the quantity of lubricant has a decisive influence on friction. Overall, the results show a good correlation between the tribological
conditions and the friction coefficient. It can be seen from these results, that even small material property fluctuations have an impact on the tribological behavior.

6. Conclusion

Within the present contribution, an approach for recording the material properties on a running strip, with regard to their tribological conditions, is presented. The described investigations have shown that the optical inline sheet roughness measurement is influenced by the lubricant on top of the coil surface. Therefore, a correction factor has been determined, to amend the falsified values. As there is a thin lubricant film on the surface, the measured roughness values are only slightly falsified. In addition, the comparison of optical and tactile measurements have shown a good accordance. The results of inline measurement have shown only slight fluctuation in strip length direction, whereas the variations across the coil width show a clearer difference. Furthermore, the results of the strip drawing test, carried out on strips of three batches, have shown that small deviations of tribological properties have an effect on the friction behavior. Even if the lubricant quantity has a decisive influence on the friction behavior, the roughness should not be neglected. Nevertheless, the optical roughness measurement offers a suitable method for recording batch fluctuations on a running strip, which can be utilized for further investigations on the tribological behavior. Thus, the presented evaluation method enables the investigation of batch fluctuations in series production.

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