

Fig. 4: Selectively oxidised $\alpha\text{-Fe}_2\text{O}_3$ specimen. Top: photo of untested specimen; mid position: digital light microscopic image; bottom: SEM image

Depending on the number of test cycles the surface of the specimens changed after the wear tests. In Fig. 5 the tested specimen A1 is shown after 100 strokes. The photo (top picture) in Fig. 5 presents the macroscopic appearance of the specimen after testing. While in the bending area of the sheet metal (0° angle) a layer thinning can be seen, the evaluated area (45° angle) shows no significant changes on the surface on the macroscopic scale. In addition, slight marks on the left and right side in the contact area with the sheet metal can be seen in the photo in Fig. 5. These are results of the sheet metal burr cutting into the surface. This phenomenon is increasing with the number of strokes but not relevant in the present context because in commercial deep drawing operations such contact conditions are not present.

The light microscopic image of specimen A1 (middle image Fig. 5) only shows slight changes as compared to the light microscopic image of the untested specimen (Fig. 4). Only a few additional scratches along the sliding direction (vertical in the image) can be seen. Furthermore metallic sparkling areas are now visible and it seems that the size of these areas has also increased. It can be assumed that their higher fraction is a result of a partial removal of the $\alpha\text{-Fe}_2\text{O}_3$ structure. The $\alpha\text{-Fe}_2\text{O}_3$ also covered the edges of chromium rich precipitations. This leads to the conclusion that the increased fraction of the oxide-free areas can be reasoned by the reduced bonding of the oxide to the substrate at these chromium rich areas. In the SEM image in Fig. 5 (bottom picture)

the surface appears very different, as compared to the SEM image of the untested specimen (Fig. 4). The structure of the oxide layer seems to be smoothed and rounded but is still visible.

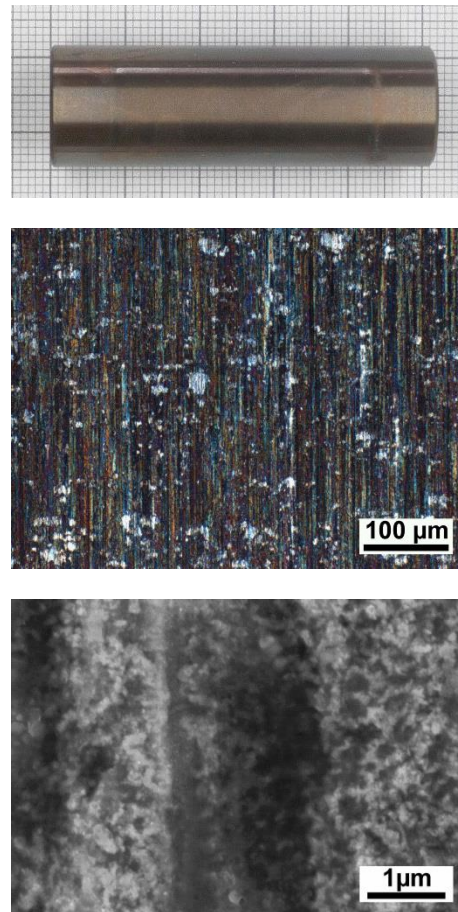


Fig. 5: Selectively oxidised $\alpha\text{-Fe}_2\text{O}_3$ specimen after 100 strokes; top: photo of tested specimen; mid position: digital light microscopic image; bottom: SEM image

After a substantial increase of the number of strokes to 5000 a thinning of the $\alpha\text{-Fe}_2\text{O}_3$ layer can be seen clearly at each magnification (Fig. 6). The photo in Fig. 6 (top) reveals that the layer has become thinner over the whole contact area. But even after 5000 strokes a remaining layer can be seen clearly also in light microscopic image (middle). In addition to the layer thinning the middle image shows scoring in the drawing direction. Also zinc pick-up from the hot dip galvanized sheet metal used was detected by EDX. The SEM image in Fig. 6 (bottom) clearly shows features that are an evidence for the existence of $\alpha\text{-Fe}_2\text{O}_3$ on the surface.

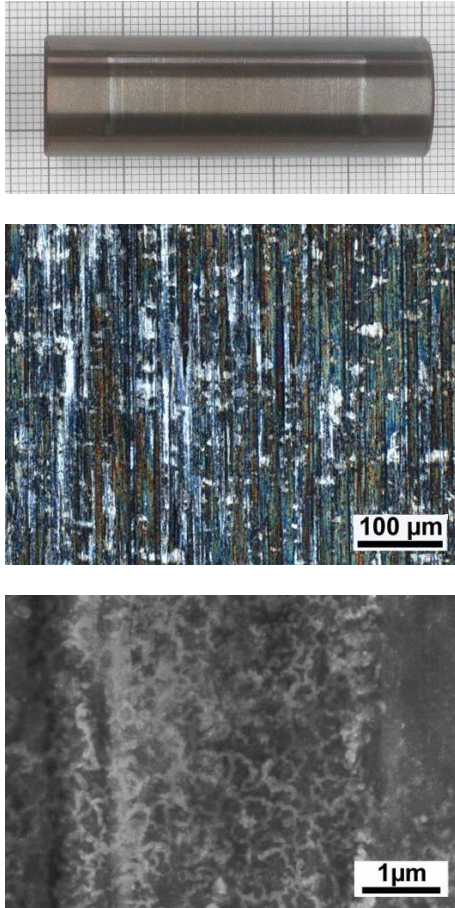


Fig. 6: Selectively oxidised $\alpha\text{-Fe}_2\text{O}_3$ specimen after 5000 strokes; top: photo of tested specimen; mid position: digital light microscopic image; bottom: SEM image

4 Summary and Outlook

Within the present study wear experiments on specimens with selectively oxidised $\alpha\text{-Fe}_2\text{O}_3$ layers were conducted with a surface pressure of 80 MPa at a process temperature of 80 ± 5 °C. The results can be summarized as follows:

It was shown that the generation of the oxide layer depends on the local composition of the surface. Surface near chromium rich precipitations were usually not covered by $\alpha\text{-Fe}_2\text{O}_3$, and thus, a complete coverage of the specimens was not realised.

Even after 5000 strokes of load (300 m of sheet metal) the friction reducing $\alpha\text{-Fe}_2\text{O}_3$ was still present on the surface, which indicates the potential of these coatings for demanding applications in dry metal forming.

Small amounts of zinc were detected on the oxidised specimen that was tested up to 5000 strokes. Whether the transfer of zinc adds to the durability of the coatings is, however, not clear yet.

It appears that oxidised surfaces might be a viable approach to realise dry metal forming as the oxides provide for low friction coefficient and feature substantial durability. Clearly, further studies need to address the tolerable maximum surface pressure between the sheet metal and specimen and how pressure affects the wear behaviour over extended periods of usage.

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