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Slider on Sheet Tester Development for Characterizing Galling

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Abstract. The overwhelming majority of automotive part manufacturing processes successfully process hot dip galvanized sheet metal. However, there were reported situations were abrasive wear (galling), visible as narrow and long scratches, was observed on the surface of the formed parts. Investigations using a Slider On Sheet Tester (SOST) were performed in order to determine the conditions that lead to scratch forming on the galvanized sheet metal surface and to identify parameters that would guarantee a scratch free situation. The tests identified the tool roughness and the contact pressure as important parameters governing the coating wear phenomena. The tests proved that the coating resists relative high contact conditions in case of smooth tool surface, explaining why in the large majority of the industrial applications coated materials can be used without issues.

Introduction

Hot dip galvanizing of steel sheet metal with a soft Zn layer is the current industry standard method to increase the corrosion resistance of the material used to manufacture the parts of automotive bodies. During sheet metal forming of automotive components, regions of the coated metal blanks slide along the surfaces of the forming tools experiencing relatively high contact pressure conditions. The overwhelming majority of automotive part manufacturing processes successfully process hot dip galvanized sheet metal. However, there were reported situations were abrasive wear (galling), visible as narrow and long scratches, was observed on the surface of the formed parts.

During forming of Zn coated sheets, part of the coating can be separated from the sheet material as flake shaped particles. The thickness of such a flake is typically a few microns while the length and width are usually at least 10 times larger. Such particles can attach to themselves or to the tools. Galling occurs when the Zn particles attach to the tool surface and form lumps that subsequent scratch the surface of the coated sheet metal. Different test set ups are used to investigate the galling mechanism in sheet metal forming, such as the strip draw test, bending over a radius, slider on sheet test [1,2], friction coupling bending [3], Twist compression test [4, 5] or benchmark parts. Each of these test set ups have their own pro's and con's related to necessary amount of tests, deformation or only sliding, etc. Several conventional tribo-tests such as rotational tests and draw tests only generate data linked to one stroke in an press part. For characterization of galling it is so important to have enough sliding distance of fresh material. Heide et al. used the Slider on Sheet Tester (SOST) to investigate the influence of lubricants and tooling on galling and tool wear [2, 6]. Specific for these investigations were the use of a double curved tool resulting in point contact between the slider and the flat metal sheet. In these investigations the coefficient of friction (COF) diagram was used as a criterion to judge whether galling would take place. The contact resulted pressures around 550 MPa [1], which is relatively high which could influence the wear behavior/mechanism.

Initiation, growth and failure of junctions between the tool and zinc coating is key in the galling mechanism. Surface defects (such as grinding scratches and holes) acts as traps for particles which stick to the tool surface [7]. Van der Heide [1] showed with an asperity model that failure at asperity level (galling initiation) can be reduced by tool surface engineering (lower Ra). Another aspect which could play a role by an increase in tool roughness is the ability to more easily entrap wear debris in the valleys and thereby increase rate of galling.

In this investigation the galling test on the SOST is further developed by changing the contact situation to a line contact. Advantages of this test will be a large test distance on fresh material and the ability to investigate galling on asperity level and the lower contact pressures compared to point contact. An experimental program was started to investigate the conditions that lead to scratch forming on the galvanized sheet metal surface and to identify parameters that would guarantee a scratch free situation. Therefore, the effect of pressure and tool roughness on scratch formation are investigated.

Industrial Observations

In most cases hot dip galvanized sheet metal can be successfully processed by automotive part manufacturers. However, sometimes narrow and long scratches (galling) are observed on the surface of the formed parts (Fig. 1a). At the position of the scratches, the coating material was partially removed by tool surface asperities. Coating flakes transported by the sliding sheet tend to accumulate near the regions of high contact pressure, usually in the draw bead areas (Fig. 1b). These accumulated flakes on the tool can cause new scratches on the parts or increase the width and depth of existing cracks. Besides galling, loose zinc particles trapped between the punch and stretched sheet material can cause high spots (Fig. 1c). Removal of the flakes, tool cleaning, is often needed resulting in additional costs for the part manufacturing process associated to the down time.

Industrial requirements on galling are diverse. It is common to consider a maximum scratch depth of the order of 0.15 μm as the maximum acceptable limit. Such a limit is related to the maximum surface defect that could be masked by the paint system [2] to an acceptable surface quality level. To tackle galling several options exist, modification of the forming tool surface by polishing, hardening and/or coating or by the use of extra lubrication in addition to the mill applied lubricant usually present on the sheet metal.

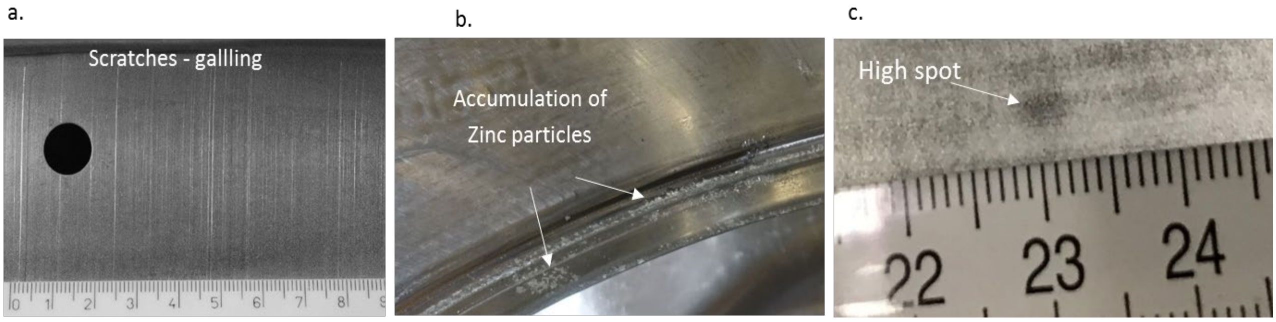

Fig. 1. a. scratches on a GI coated part, b. coating accumulation on the die in the drawbead area, c. example of a high spot produced by a Zn flake.

Analysis of particles collected from industrial press trials showed that individual flakes of Zn were compressed and compacted to each other (Fig. 2a). The flakes are composed of Zn only (no Fe is measured), suggesting that the scratches are superficial and no significant abrasive wear of the tool occurs and only the coating of the sheet material is removed. Careful examination of the individual flakes on both sides, shows on one side the EDT topography (Fig. 2b) while on the other side (Fig. 2c) fine scratches are visible revealing the cut direction of the tool surface asperity.

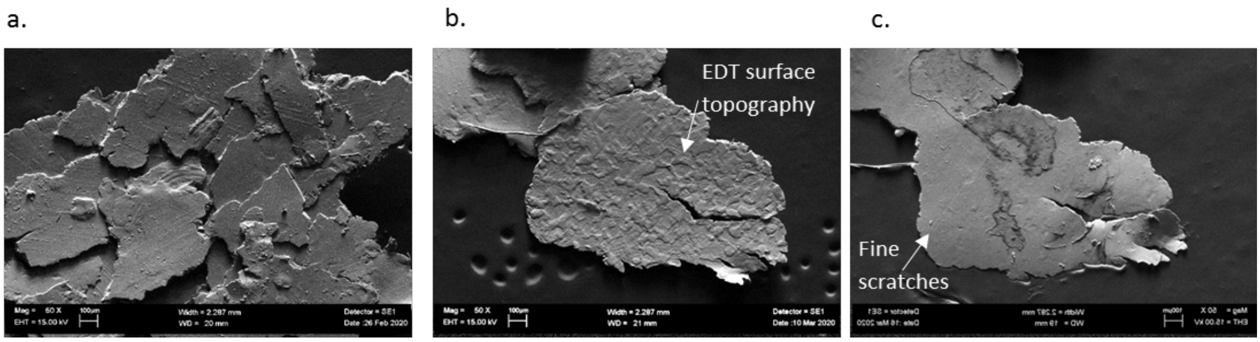

Fig. 2. SEM images a. Zn flakes accumulated and compacted b. individual zinc flake with EDT surface texture topography, c. the opposite side of the flake b. – smooth surface with fine parallel scratches (mirrored image).

Material and Methods

An experimental program was started to investigate the conditions that lead to scratch forming on the galvanized sheet metal surface and to identify parameters that would guarantee a scratch free situation. The experiments were performed using a Slider On Sheet Tester (SOST) capable of providing controlled well-defined contact conditions between the tool surface and metal sheet. Tests were performed for line contact at different pressure and tool texture.

In the SOST a cylinder is attached on a slider and pressed against the sheet material. Two values of a controlled normal pressure of 1 respectively 2 bar (resulting in normal load of 120 and 290 N) were used. The two loading levels result in nominal pressures of approximately 150 and 235 MPa respectively. The slider moves 1450 mm in x direction (Fig.3) with a certain velocity (50 or 100 mm/s). After the track length, the slider is lifted up and brought into a new position (x=0 and y = 10 mm). At this new position, the slider is again pressed upon the sheet and moves again 1450 mm in x-direction. In this way, every time virgin material is in the contact with the moving tool. In these test 37 tracks are performed, which means that 54 m of sliding length is achieved. As an approximation, this sliding length could represent drawing of 540 parts. For each test the ring is slightly rotated and mounted such that for each test also a fresh tool material is into contact. Alignment of the tool is of utmost importance and a well alignment is ensured by using pressure paper.

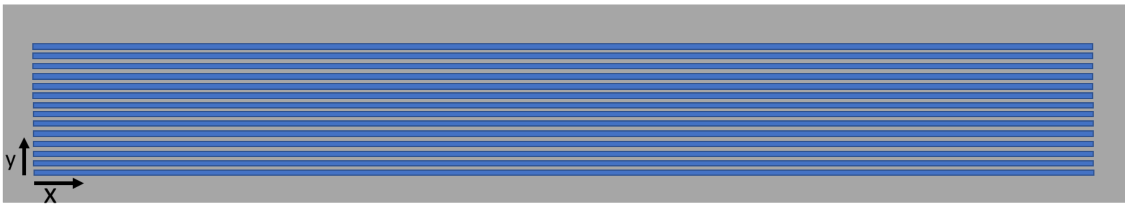

Fig. 3. Schematic view of sheet with tracks.

The sheet material under investigation is 0.8 mm DX56 GI material with lubricant N6130 1.5 g/m^2. The roughness values of the tools and sheet are listed in Table 1. The tool material is a WN 1.2379 with a hardness of 60±2 HRC. The slider (cylinder) has a diameter of 43 mm and contact width of 6 mm.

Table 1. Characteristic roughness values of the sheet and tool material ISO 25178.

	Sa (µm)	Sq (µm)	Sp (µm)	Sv (µm)	Sz (µm)
Sheet	0.71	0.85	2.89	3.28	6.17
Tool 1	0.30	0.39	1.65	2.39	4.04
Tool 2	0.71	0.92	2.99	8.50	11.5
Tool 3	1.71	2.37	10.2	12.4	22.7

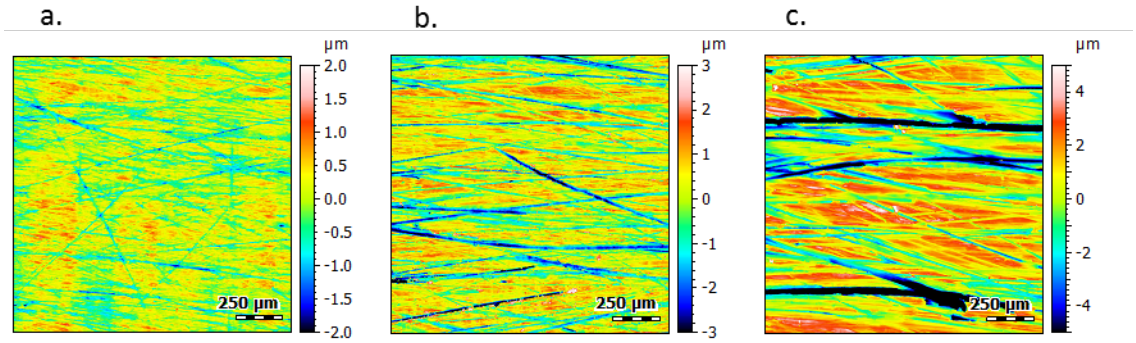

Fig. 4. Confocal measurement tool surface a. Tool 1 b. Tool 2 and c. Tool 3.

Three dimensional topography measurements of the tool and sheet surfaces were performed by a confocal microscope. Confocal measurements on the sheet were made after 50 mm drawing and at position of a clear scratch. If no scratch occurred, a confocal measurement was made after 5350 mm drawing distance. Confocal measurements of the tools were made before the tests and after the tests (Fig. 4). Before the tool confocal measurement, the tool is cleaned with a tissue with acetone to remove loose particles.

Results and Discussion

Ploughing tracks and or scratches are visible from the start of the tests, particles build up on the tool and sometimes particles fall off on the sheet. At higher tool roughness additional scratches occur after a certain track length (Fig.5a). Sometimes these scratches disappear again if the scratching asperity particles breaks out of the contact. After cleaning the tools by a tissue with Acetone, a confocal measurement is performed on the tools. The tools shows clearly adhesive wear build up onto the tools trapped in the valleys (Fig 5b and c). SEM/EDX measurements are necessary to determine whether abrasive wear also occurred.

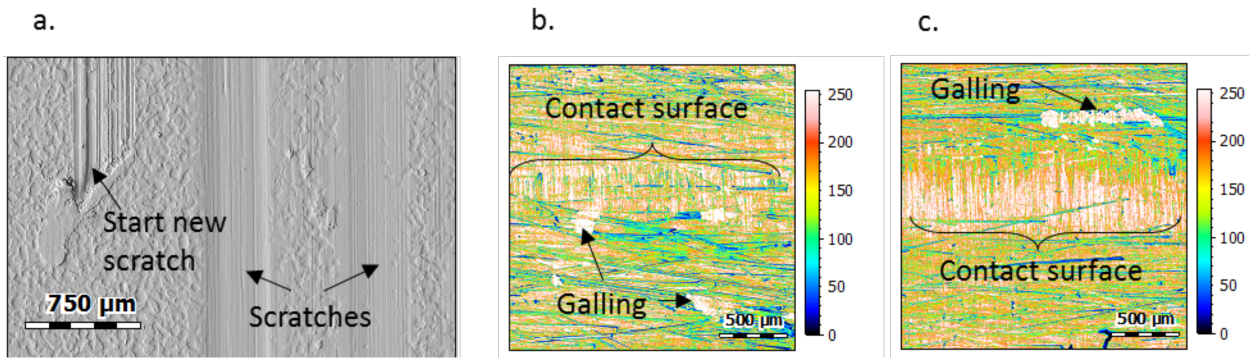

Fig. 5. Confocal measurement. a. visible scratches in sheet (tool 0.7 µm-_2 bar) b. Light intensity tool surface 1 (Sa 0.3 µm – 2 bar) c. Light intensity tool surface 1 (Sa 0.7 µm- 2 bar).

Effect of tool roughness. Experiments with three different tool roughness are performed, namely Sa 0.3, 0.7 and 1.7 µm. Scratches in the sheet increases in amount and depth with tool roughness. In case of a 0.3 µm tool roughness some shallow ploughing tracks are observed (Fig.6a). After 54 m sliding distance, a very homogenous flattened surface is measured without any scratches (Fig.6d). The COF gradually increases with successive track numbers (Fig.7a). At the higher pressure (2 bar), some vibrations occurs in the first few tracks.

Increasing the tool roughness to 0.7 µm results in deeper ploughing tracks from the start (Fig 6b and Table 2). Also after some distance scratches occur up to 5 µm (Fig6e). The COF is higher for 0.7 than for a 0.3 µm but still relatively smooth.

The largest tool roughness of 1.7 µm results in very deep scratches immediately at 2 bar load (Fig 6c). The contact situation is also less homogenous, the contact directly localizes as one spot. The contact surface changes during the drawing distance and is at certain tracks more or less homogenous.

Several times new scratches occur somewhere in the track. The COF is less gradual than for the two other roughness (Fig 9).

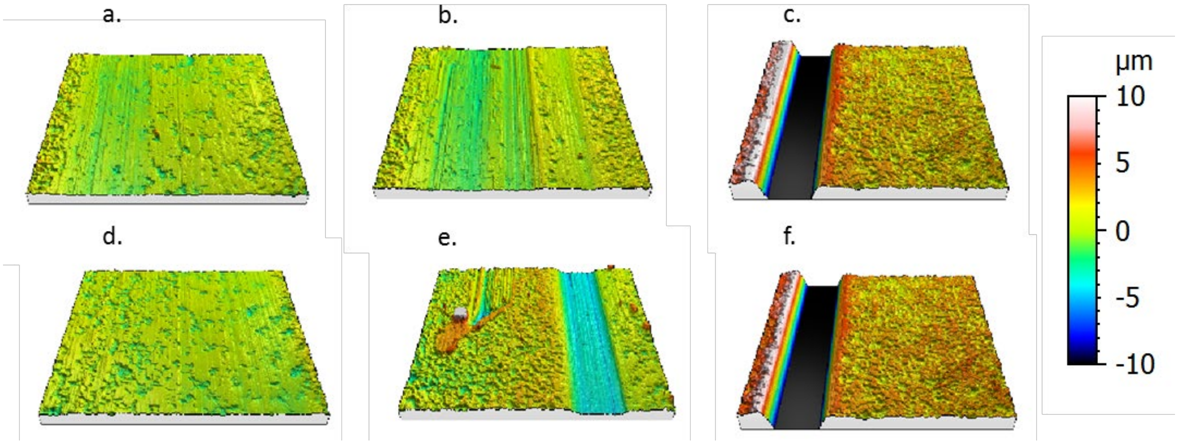

Fig. 6. Confocal measurement sheet surface (2x2 mm) 2 bar test with a tool roughness of a. Sa 0.3 µm – track 1 b. Sa 0.7 µm – track 1, c. Sa 1.7 µm –track 1, d. Sa 0.3 µm – track 37, e. Sa 0.7 µm – track 6, f. Sa 1.7 µm –track 4.

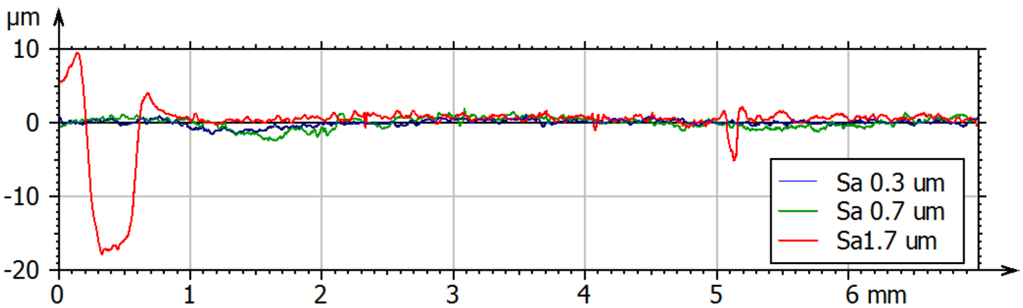

Fig. 7. Profile depth versus width over track for tests with several tool roughness after 50 mm drawing distance. Test at 2 bar.

Table 2. Max. scratch depth in tracks.

	0.3 µm		**0.7 µm**		**1.7 µm**	
	Track 1	Track 37	Track 1	Track 6	Track 1	Track 7, 4
1 bar	1.6	0.9	1.3	4.6	2.6	4.4
2 bar	1.5	1.1	2.4	4.7	17.8	19.4

Effect of pressure An increase in pressure results in increase in tool pollution and build up on the tool. More particles are collected from the tool for a higher roughness and/or higher pressure (Fig. 8). SEM/EDX analysis will be performed to investigate whether only Zn particles are build up onto the tool. In general, the COF increases with increase in pressure (Fig 9b and c). Sometimes, exception occurs at the first 10 tracks (Sa 0.7 µm) or at the last 12 tracks (Sa 0.3 µm).

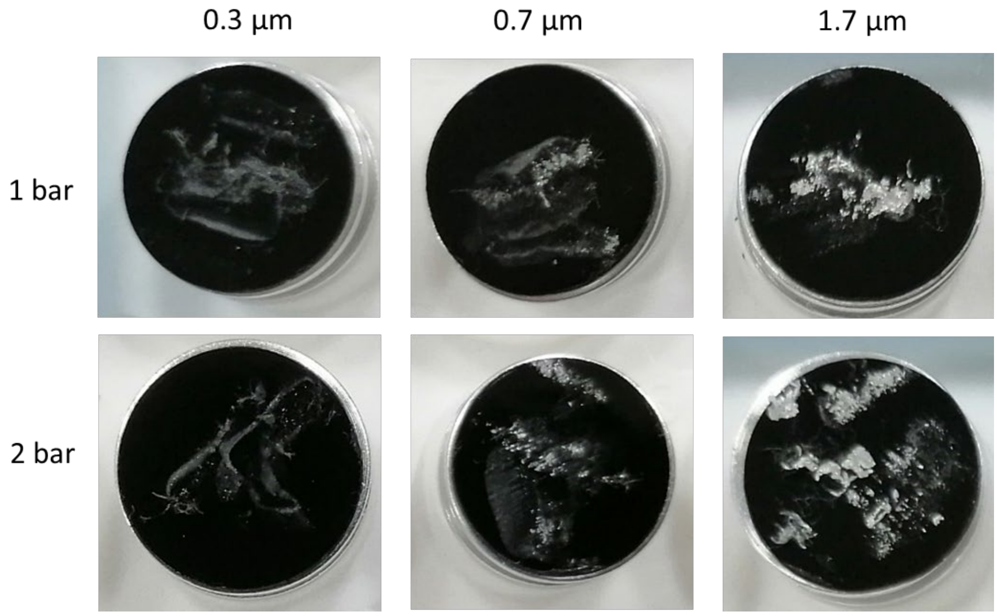

Fig. 8. Particles collected from the tools after the test (shiny particles are Zn particles).

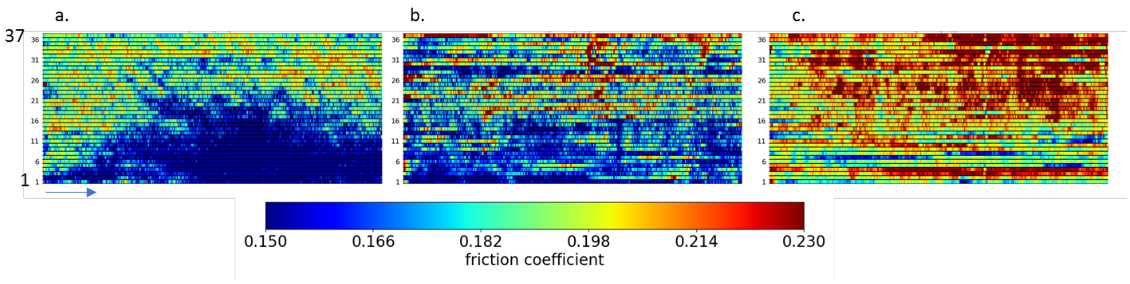

Fig. 9. Colour plot Coefficient of Friction for the tracks. a. Sa 0.3 µm 1 bar, b. Sa 1.7 µm 1 bar and c. Sa 1.7 µm 2 bar.

In general, an increase in pressure results in more severe scratches (Fig.10). This is especially observed at the highest tool roughness.

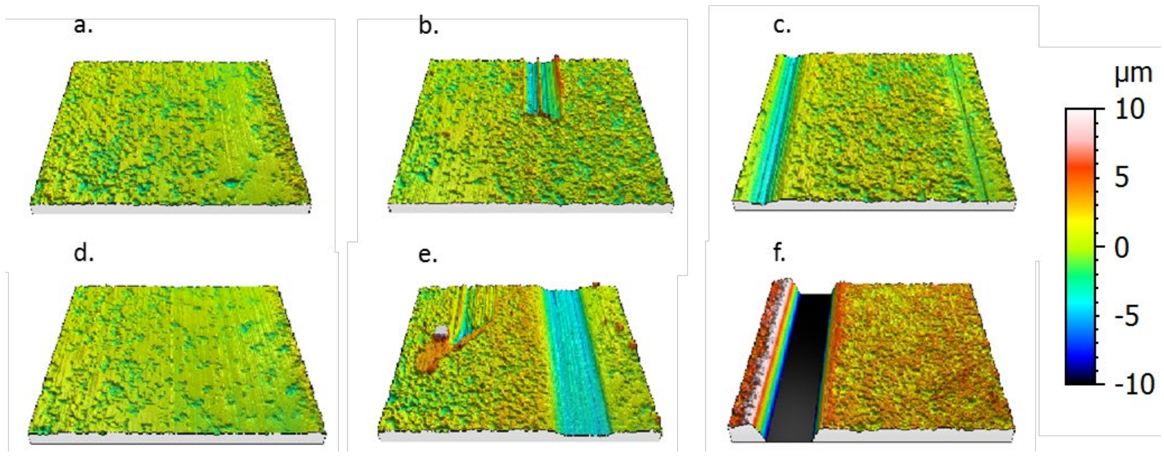

Fig. 10. Confocal measurement sheet surface (2x2 mm) a. Sa 0.3 µm track 37 1 bar b. Sa 0.7 µm track 6 1 bar, c. Sa 1.7 µm track 7 1 bar, d. Sa 0.3 µm track 37 2 bar, e. Sa 0.7 µm track 6 2 bar, f. Sa 1.7 µm track 4 2 bar.

Conclusions

The key findings of this investigations are as follows:

- The wear mechanisms observed in these tests are compared to the observations from industry.
- The test identified the tool roughness and the contact pressure are important parameters governing the coating wear phenomena.
- The tests proved that the coating resists relative high contact conditions in case of smooth tool surface, explaining why in the large majority of the industrial applications coated materials can be used without issues.
- Increasing tool roughness resulted in coating detachment, similar to that observed in industrial applications. Further tests are aimed at quantification of this phenomenon.
- Accurate tool alignment was crucial for obtaining reliable results.

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