

## Tool Wear Investigation Nickel Plated Steels for Battery Shell Production

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**Abstract.** Nickel coated steel is used in the industry to produce battery shells. These shells are typically produced in several process steps: drawing, redrawing and several ironing steps at high production rates. The nickel plated steel sheet is subjected to a large range of deformations and pressures. Sometimes scratches in the longitudinal direction of the shell (hairlines) occur, due to the build-up of particles on the tooling (i.e. galling). Cleaning of the tools will be necessary and will bring additional costs. In this paper, analyses are performed on tribological behaviour of nickel plated steel sheet with the focus on tool wear. Adhesive wear has been observed to be the main wear mechanism. The adhesive layer build up consists mainly of compacted particles (often in the shape of flakes) of nickel and iron. The Slider on Sheet Test (SOST) is found to be a relevant set-up to study tribological behaviour of nickel plated steels in battery production.

### Introduction

Battery shell manufacturers process nickel (Ni) plated steels in large scale successfully. Battery shell production typically exists of several forming steps: drawing, redrawing and several ironing steps. Sometimes scratches in the longitudinal direction of the shell (hairlines) occur due to the build up of particles on the tooling (i.e. galling). Cleaning of tools will be necessary to avoid scratches. This will lower production rate and bring additional costs.

For both non rechargeable (primary) and rechargeable (secondary) batteries a nickel coating will provide corrosion protection. For the primary batteries, the nickel coating will also reduce the contact resistance at the inside of the battery. In the process of forming a battery shell, the nickel coating is subjected to a large range of deformations and pressures which leads to the creation of wear particles. Over time, these particles can attach and build up on the tools. In case the build-up become too severe, scratching of the battery shell occurs. Factors influencing the friction and wear could be, amongst others, surface topography, hardness [1], brittleness [2] and microstructure [2].

Several prior studies have investigated the tribological and wear properties of Ni and Ni-based coatings [1-4]. Gawne and Ma [2] investigated friction and wear of chromium and nickel coatings and found that adhesive wear was the dominant wear mechanism (except for the scratch test). No direct correlation was found between hardness and wear rate for chromium plating, electroless and electroplated nickel coatings. Instead, an influence of phase, brittleness, and scratch indentation size was observed.

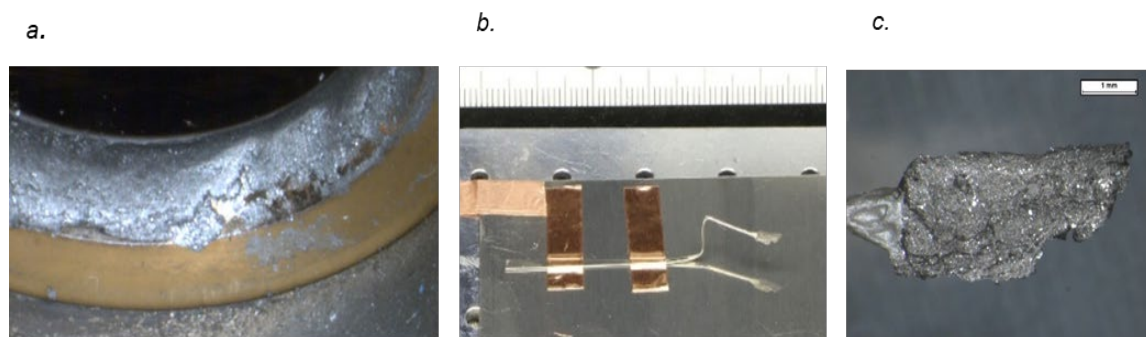
Several test set-ups exists to investigate tool wear in sheet metal forming, such as slider on sheet [5], strip draw test, friction coupling stretch bending [6], scratch test [2], twist compression test [7] or benchmark parts. Test set ups can include or exclude deformation, include different sliding lengths and pressures. A large advantage of the slider on sheet tests is enough sliding distance of fresh material [5]. Several investigations are published [5, 8] with the Slider on Sheet Tester (SOST) regarding influence of lubricants [5], roughness of tooling and sheet [8] for Zn coated steel sheets. Several different tool (slider) geometries are used, resulting in different contact pressures such as a double curved tool (point contact) or a single curved tool (line contact).

In literature, limited information can be found on the occurrence and tool wear mechanism related to production of battery shells. In this paper, tool wear in battery production is investigated. First of

all an SEM/EDX analysis is performed on the tool wear of a 2<sup>nd</sup> ironing ring from an industrial production facility. Secondly lab-scale SOST tests and SEM/EDX analyses are performed to investigate whether this test set-up is representative to industry.

### Industrial Observations

Sometimes during the battery shell fabrication small scratches in the longitudinal direction (hairlines) occur. These scratches are related to tool pollution. After a certain production time, tool pollution is often quite severe and after some time tools need to be cleaned. A layer of particle build up is clearly visible on the production tools (Fig.1a). The interval between required cleaning operations varies depending on process conditions, however in some combinations of material and process set up this can already occur after some hours. In this investigation, the production process consists of six forming steps: one drawing step, one redrawing step and four ironing steps. Tool wear is observed in all these forming steps of the battery shell and occurs for both high and low production speeds (110 strokes per minute vs 70 strokes per minute).



**Fig. 1.** a. Tool pollution on 2<sup>nd</sup> ironing ring b. lump of tool wear fixed with silver paint on a needle. c. investigated lump of tool wear.

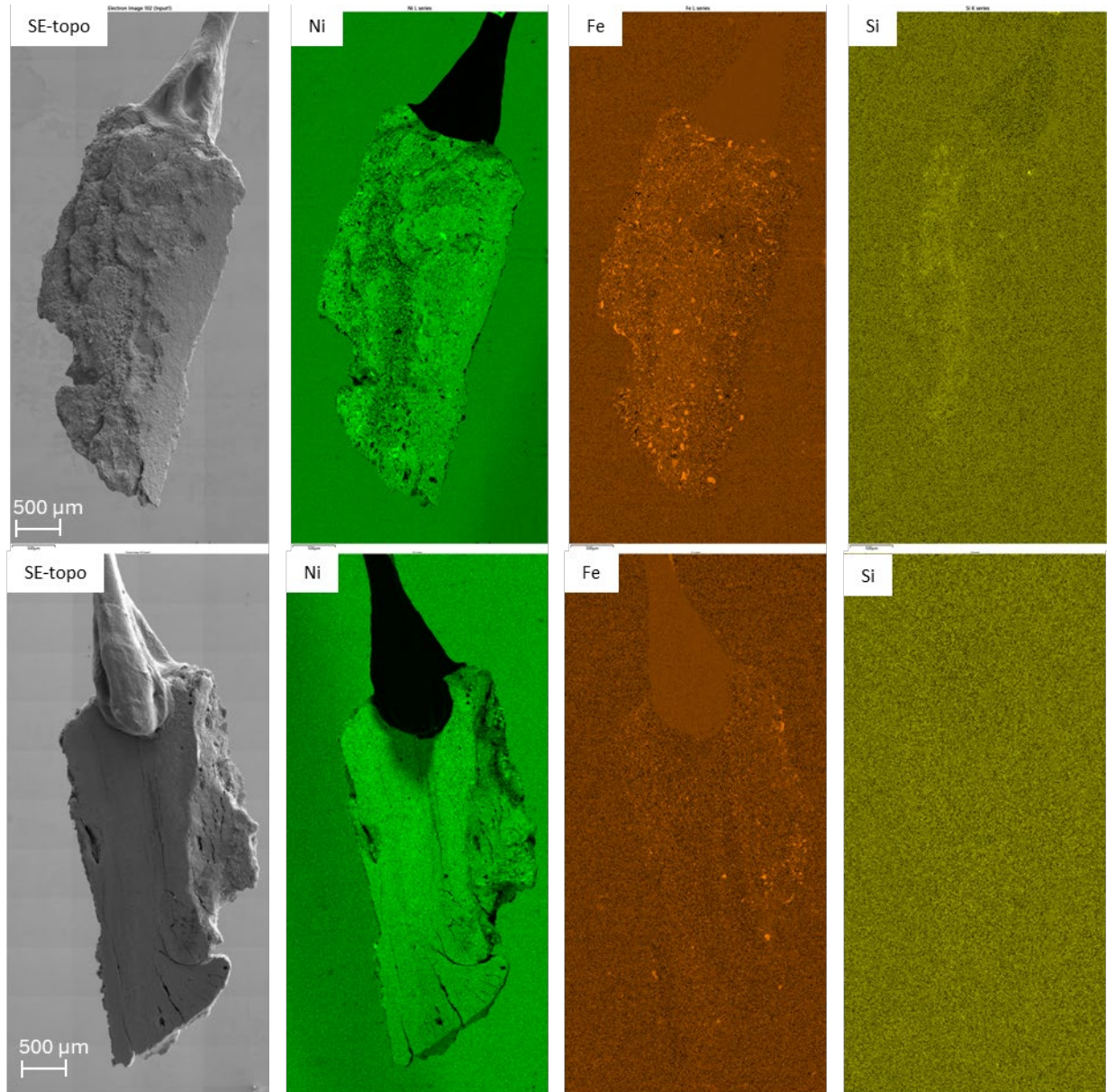
### Materials & Methods.

The tool pollution from the 2<sup>nd</sup> ironing ring is analysed by scanning electron microscopy (SEM/EDX). The tool material is Titanium Carbide with 2.89 % C, 29.71 % N and 67.40 % Ti (mass percentages). A part of the tool pollution is carefully removed from the tool and fixated with silver paint on a needle (Fig.1b). In this way it is possible to analyse both sides of the tool pollution. Fig.1c shows the lump of tool pollution which is investigated. The smoother area on the left side of Fig 1c, is the silver paint used to attach the tool lump to the needle.

The nickel plated steel sheet has a steel substrate thickness of 0.35 mm with a Ni coating of 1.5 and 2.0  $\mu\text{m}$  on the inside side and outside respectively. The 2  $\mu\text{m}$  is the outside of the battery shell. The complete production process is as follows: bare steel substrate is cold rolled, electroplated with nickel, annealed and temper rolled. The final sheet material has a yield strength ( $R_p$ ) of 245 MPa and an tensile strength ( $R_m$ ) of 366 MPa.

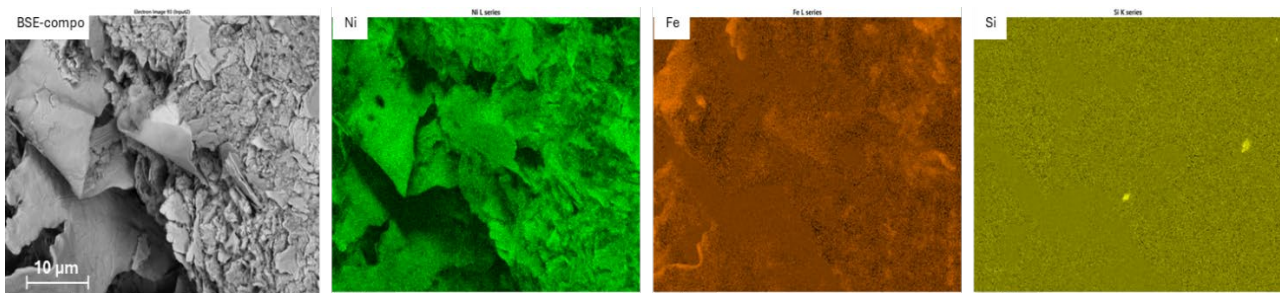
### Results.

Fig.2 shows SEM mapping analyses of the tool pollution obtained from the 2<sup>nd</sup> ironing ring. The tool side (Fig.2 top row) has a relatively rough appearance compared to the sliding side (Fig.2 bottom row). In the sliding side the tool pollution is smooth due to the sliding at high pressures. The tool wear is also relative smooth (Fig.2 top row) at the contact area with the tool. The rougher surface in the same image is the fractured surface caused by removing the tool wear from the tool. The tool pollution exist mainly of nickel rich particles and iron particles. Nickel and iron particles originate from the sheet coating. Less iron particles are visible on the sliding side than on the other side. Some silicon is observed and could originate from the lubricant. The main wear mechanism is adhesive wear.



**Fig. 2.** SEM SE topo and mapping images of lump of tool wear 2<sup>nd</sup> ironing ring. Top row: Tool side, Bottom side: Contact sheet side.

SEM images (Fig.3) of the tool lump clearly shows individual flakes and particles, which are compacted to each other to form a large deposit on the tool. The flakes consist mainly out of Ni and iron. Different size of particle are observed, small ones ( $\sim 2 \mu\text{m}$ ) and larger ones ( $> 10 \mu\text{m}$ ). Adhesive wear is the main wear mechanism, and the deposits on the tool consist mainly out of particles from the sheet material.



**Fig. 3.** SEM BSE composition and mapping images of particles from tool wear 2<sup>nd</sup> ironing ring.

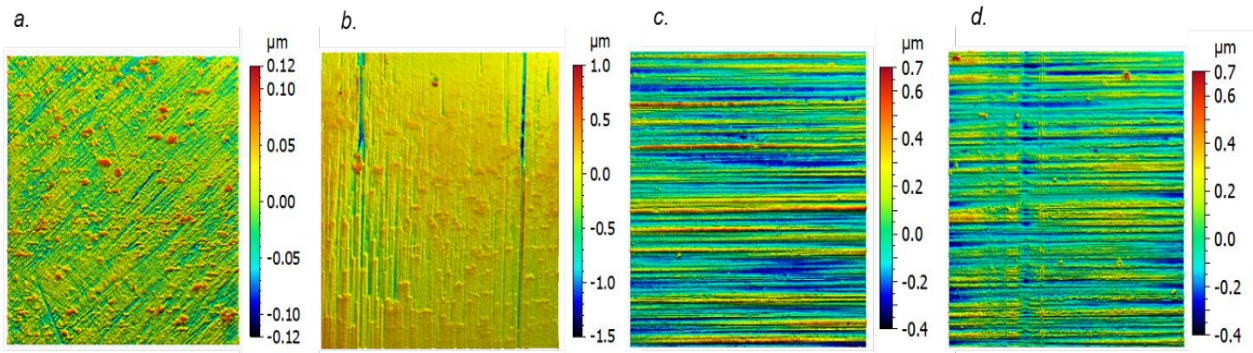
## Lab Galling Test

Lab test on the Slider on Sheet Tester (SOST) are performed to investigate scratch forming and wear particle generation on Ni plated sheets. The results are compared with the industrial observation to check the lab test represents the industrial situation well.

### Materials and Methods

A (cylindrical) SOST slider tool is pressed against a nickel plated sheet using an air cylinder at pressures of 0.7 bar and 1 bar. These pressures result in a normal force of 115 N and 165 N respectively, corresponding to mean contact pressure of approximately 160 MPa and 190 MPa. During the test, the slider is drawn over a 700 mm path on the sheet. At the end of each stroke, the slider is lifted and repositioned 10 mm next to previous track. This procedure is repeated to produce forty-two parallel tracks on a single sheet. Two sheets are used for each test set up, resulting in total sliding length of 58.8 m. For each test set-up, three repetitions are conducted. The sliding direction is oriented perpendicular to the rolling direction.

The Ni plated sheet used is standard production material with a thickness of 0.3 mm. The coating thickness is different for both sides (4 and 1  $\mu\text{m}$ ). The tests are performed on the 4  $\mu\text{m}$  coating side. Dimensional topographical measurements are performed with a nanofocus  $\mu\text{surf}$  mobile confocal microscope before and after testing on the surface of the material (Fig.4). The height parameters of the material are listed in Table 1. Sample sheets are lubricated with Renoform MBW 677/6 25% which is applied using a pipet and distributed with a foam roller on the material, such that the lubricant amount is  $\sim 0.75 \text{ g/m}^2$ . The same kind of lubricant is used in industry, however the exact composition and percentage could differ.



**Fig. 4.** Confocal measurements 600 x 600  $\mu\text{m}$  a. initial tool surface. b. Tool surface after test c. initial sheet surface. d. sheet surface after test.

**Table 1.** ISO 25178 height parameters initial tool and sheet surface.

	$Sa$ [ $\mu\text{m}$ ]	$Sp$ [ $\mu\text{m}$ ]	$Sv$ [ $\mu\text{m}$ ]	$Ssk$ [-]	$Sku$ [-]
Tool	0.05	0.24	0.28	-0.28	3.71
Sheet	0.14	0.69	0.41	0.84	3.43

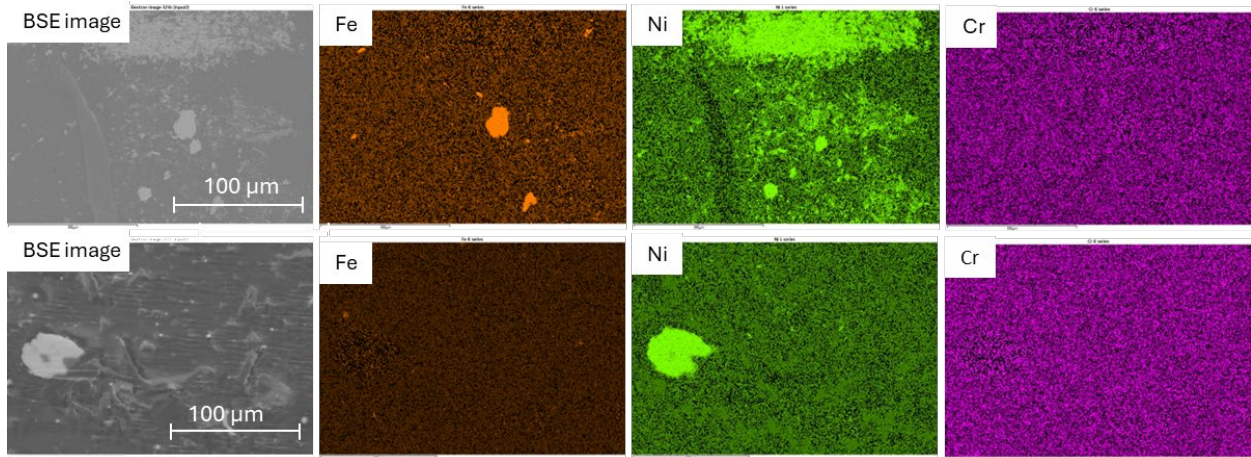
The slider tool material is 1.2379 (EN ISO 4957) with a polished surface roughness ( $Sa$ ) of  $\sim 0.05 \mu\text{m}$  (Table 1) and a hardness of 62 HRC. Table 2 list the tool material elements. The tool diameter is 43 mm, with a total width of 8 mm and contact width 5 mm. For each new test a 'virgin' tool surface is used, by rotating and mounting the slider to a new position. Before performing the tests, the load cell is calibrated and the tool is aligned with pressure paper. After the tests, wear particles are collected from the tool for SEM analyses using suitable copper adhesive tape. Thereafter, the tool is ultrasonically cleaned and confocal measurements are performed.

**Table 2.** Tool material element in Wt%.

C	O	Si	Cr	Fe	S	V
4.29	3.16	0.43	13.05	77.37	0.39	1.31

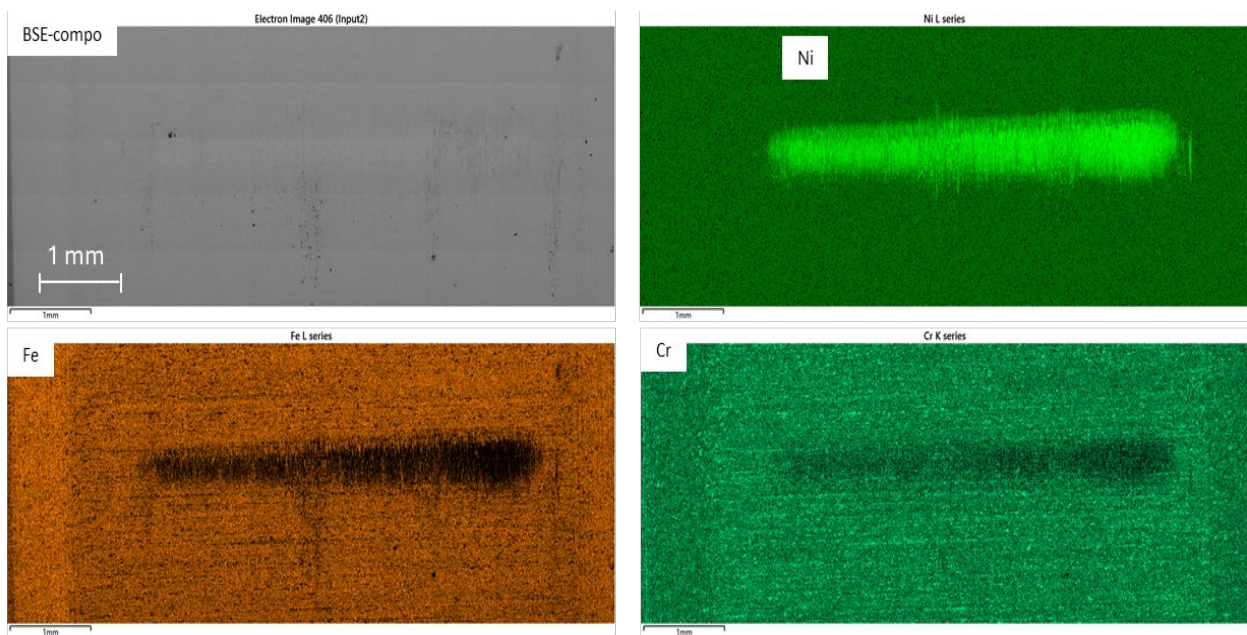
## Results and Discussion

After each test asperity flattening is observed on the sheet and sometimes a ploughing track or scratch (Fig.4d) occur. After the test (sliding length 58.8 m) the tool is polluted with particles and oil over the whole width of the tooling. Particles are collected by tape and investigated in the SEM. The composition maps (Fig.5) show a lot of O and S, which originate from the oil. A large amount of nickel particles is observed, which originate from the sheet coating. A very limited amount of chromium is measured (which can only come from the sliding tool) and thus only very limited amount of abrasive tool wear occurs. Iron particles are observed too which could originate from the tooling and/or the sheet. The size and appearance of the particles has a large range. From small particles ( $< 5 \mu\text{m}$ ) to relatively large particles up to  $50 \mu\text{m}$ .



**Fig. 5.** SEM/EDX analyses of particles collected from tool.

After ultrasonic cleaning of the tool, confocal (Fig.4b) and SEM analyses (Fig.6) are performed on the tool surface. The confocal image (Fig.5b) shows build up. SEM Nickel mapping (Fig.6) measures over the whole contact width (5 mm) nickel, which is thus adhesive wear. On the tool surface mainly particles of Ni are attached (adhesive wear). The confocal of the tool shows 'scratches'. From particle analyses, only one Cr particles is observed (from many measurements) which indicate that there is almost none abrasive wear. The main part of the observed scratches is therefore thought to be only through the adhesive wear layer.



**Fig. 6.** SEM/EDX analysis mapping elements on tool surface SOST slider.

The Coefficient of Friction (COF) shows some fluctuations (Fig. 7). In the middle of the sheet a slightly lower coefficient of friction is observed compared to the start and end of one track. This could be related to the amount of lubrication, however this is not yet confirmed. The repeatability between sheets is relatively well. One sheet out of 12 (test no. 2b) had a significantly higher COF, probably related to lubrication.

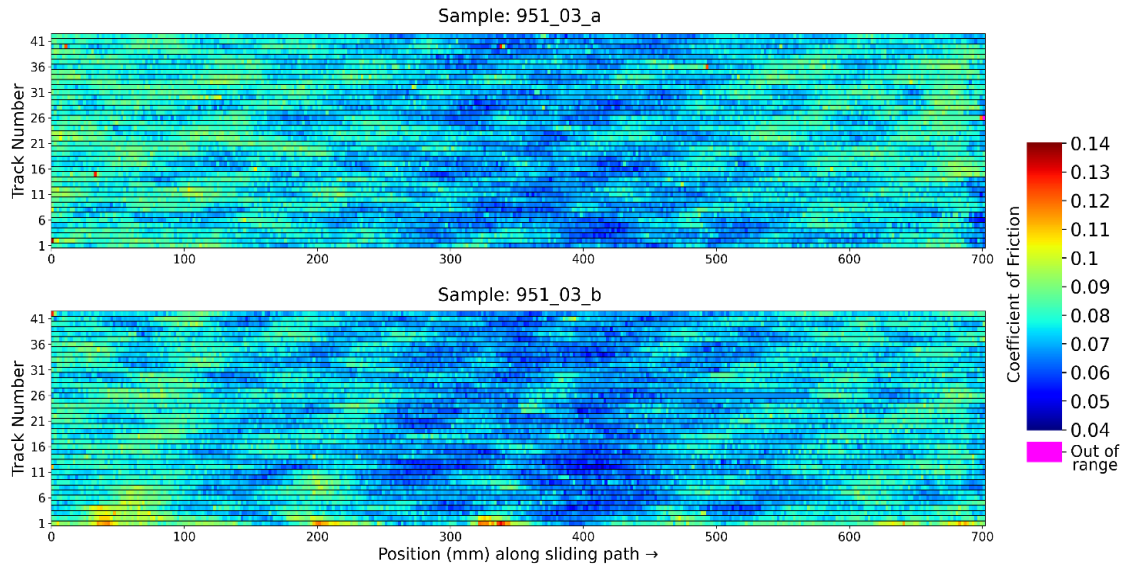


Fig. 7. Colour plot Coefficient of friction. SOST test 3 0.7 bar.

## Discussion

In ironing severe deformations (thickness reduction), high contact pressures and an increase in temperature occur. These conditions are not represented in the laboratory tests, yet they significantly influence the friction and wear behaviour of the nickel coating. The deformation, pressure and rise of temperature will affect both the mechanical response and fracture behaviour of the Ni coating. Plastic deformation of the sheet increases the real area of contact, which in turn alters frictional behaviour. At this moment, the galling behaviour is investigated without these effects.

The lubricant amount was relatively low in the lab test (SOST) compared to industry, to accelerate tool wear. However, this could have resulted in another friction regime than what is typical for industry. Since the focus for this investigation is on tool wear, this disadvantage is accepted. In the future, an investigation could be performed to investigate the influence of lubricant amount on (tool) wear.

The tool in the laboratory investigation was softer than the tools used in industry (carbide), which could result in more abrasive wear for the laboratory tool. No significant amount of abrasive tool wear is observed in the laboratory set up. In both set-ups (industry and lab test) mainly adhesive wear is observed. Due to the fact that the sliding tool in the lab set-up is made of steel, the possibility of metal-metal bonds could also increase the likelihood of adhesion occurring. A carbide tool is perhaps less susceptible to this effect.

Different types of tests can be performed with the SOST. In this paper, long drawing lengths are performed and the tool wear is analysed. Another option is to gradually increase pressure until a scratch occurs. In this way the strength of the coating is tested and an indication is obtained for the sensitivity to galling. An advantage is the lower amount of sheet necessary to test, which could be relevant for new material developments.

Both test series (lab + industry) were carried out using production material, however the Ni coating thickness differed between them. Differences in coating thickness may influence galling behaviour, as a thicker Ni layer has a higher amount of metallic Nickel present at the surface. The significance of this effect needs to be further investigated.

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## Conclusion

In this paper, SEM/EDX analyses were performed to assess the tribological behaviour of nickel plated steel sheet with a focus on tool wear. The layer build up consists of compacted particles (often in the shape of flakes) and is composed mainly of nickel with some iron content. Slider on Sheet Tests (SOST) is found to be a relevant set up for studying tribological behaviour of Ni plated steels in battery production.

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