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# Reduction of wear on pinch rolls in hot strip mill

### Zusammenfassung

Die Warmbreitbandstraße für Flachprodukte ist ein wichtiger Prozessschritt der Stahlbandproduktion. In den letzten Jahren wurden beträchtliche Fortschritte erzielt, um die Ursachen des Oberflächenverschleißes von Arbeitswalzen beim Warmwalzen, insbesondere beim Bandwalzen, zu verstehen. Dennoch besteht bei den Walzwerkkomponenten nach wie vor ein hoher Bedarf für Verschleißschutzmaßnahmen. Das Projekt "ReduWearGuid" hat zum Ziel, den Verschleiß von mechanisch und thermisch hoch belasteten Bandführungskomponenten in Warmwalzwerken zu reduzieren. Hauptziele sind die Erhöhung der Lebensdauer von Bandführungskomponenten, die Reduzierung von Produktionskosten und Stillstandzeiten, die Erhöhung der Zuverlässigkeit und Sicherheit sowie die Reduzierung von Oberflächenfehlern am Band. Hier werden die Treiberrollen fokussiert. Sie befinden sich im Bereich zwischen dem letzten Fertiggerüst und vor dem Haspel. Ihre Funktion besteht in der Aufrechterhaltung der Bandspannung und der Bandführung (Umlenkung) zum tiefer liegenden Haspel. Aufgrund der hohen Bandtemperaturen müssen die Treiberrollen mit Wasser gekühlt werden. Die Hauptursache des Treiberrollenverschleißes ist Abrasion zwischen Band und Treiberrollen. Der Verschleißeffekt wird durch Abriebpartikel der Bandkanten und Bandseitenführungen sowie durch Verluste der Rollenmaterialfestigkeiten, infolge der Kontakttemperatur zwischen Band und Rolle, verstärkt. Aus diesem Grund müssen die obere und untere Treiberrolle regelmäßig nachgeschliffen werden. Zur Reduzierung des Treiberrollenverschleißes werden zwei Ansätze untersucht: (i) Einsatz von Schmierung und/oder (ii) einer innovativen Verschleißschutzschicht.

Bezüglich der Schmierstoffe werden hier wasser- und ölbasierte Schmierstoffe favorisiert. Bei den Beschichtungen gibt es unterschiedliche Lösungsansätze: z.B.: Hartstahlaufschweißungen (aktuelle und alternative Varianten wurden untersucht), Ni/P elektrolytische Beschichtung, galvanische Hartverchromung und thermische Spritzschichten. Die Schmierstoffe wurden mittels verschiedener, bewährter Prüfverfahren (Plate Out, Wash Off und Reibungsversuchen) getestet. Die verschiedenen Beschichtungen wurden mit Querschliffen, Härtemessungen und Verschleißprüfungen wie Gummirad- und Schlagversuchen bewertet. Nach diesen ersten Screenings wurden einige Schmierstoffe und Beschichtungen ausgewählt, die in einem Hochtemperatur-Teststand (Zweizylinderrollen-Heißverschleiß Prüfstand) getestet werden sollen. Verschleißraten (Verschleißprofil, gravimetrisch), Topographie und Reibung können kontinuierlich kontrolliert und ausgewertet werden. Ein qualitativer Vergleich verschiedener Ansätze ist möglich, um den effektivsten Weg zur Verschleißreduzierung zu finden. Die Übertragung der unter Prüfstand- und Laborbedingungen getesteten Schmierstoffe und Beschichtungen auf die Größenordnungen der Produktionsanlagen (Up-Scaling) muss noch erfolgen.

### Abstract

The hot strip mill for flat products is a core part in the steel strip production. Considerable progress has been made in recent years to gain an understanding of work roll surface degradation in hot rolling, especially in strip rolling. Nevertheless for the mill components there is still high demand for wear protection. The project “ReduWearGuid” is aimed at reducing the wear of guiding components used in hot rolling mills. The main objectives are to increase the life time of guiding components, the reduction of production costs and downtimes, the increase of reliability and safety as well as the reduction of surface defects on the strip. Here, the pinch rolls are focused. They are located after the last finishing stand and before the coiler and keep the strip tension in between. Due to the high strip temperatures, the pinch roll must be cooled by water. In addition to abrasion by particles from the side guides, which deteriorate the pinch roll surface, the pinch roll is also affected by wear due to the high contact pressure between the strip and the roll. Due to this fact the upper and the lower pinch roll need to be reconditioned frequently. To prevent wear of the pinch roll, two approaches are investigated: (i) a lubrication and/or (ii) an innovative wear protective coating.

Regarding the lubricants, water and oil-based lubricants are addressed here. Regarding the coatings, really different ones are investigated: deposition welding materials (current case and new ones), Ni/P electro-less coating, hard Cr electro-galvanising coating and thermal spraying coating.

For the lubricants, they were characterised in term of plate out, wash off and friction tests. The various coatings were evaluated with metallographic analysis, hardness measurements and wear tests such as rubber wheel and impact tests. After these first screenings, some lubricants and coatings were selected to be tested in a high temperature testing device “two-rolls hot test bench”. Wear rates (wear profile, gravimetric), topography and friction can be continuously controlled and evaluated. A qualitative comparison of different approaches is possible to identify the most effective way to reduce wear. This will enable to finally select the lubricants and coatings to be tested at the plant in real size and to start the up scaling.

## Introduction, problem description

While previous European projects [1-4, 11-12] have contributed to improve understanding of wear and thermal fatigue on work rolls, only a few studies have been performed to investigate deeply the guiding components in hot strip mills. Since these components also require maintenance and affect the plant reliability and workers safety, there is a considerable need to improve their performance.

The projects [1-4] were dedicated to decrease the wear at the hot rolling process as well as to increase the strip surface quality. Also the aspects of rolling force and torque are major targets of lubrication projects. These lubricants meet the special requirements of the hot rolling process like high temperatures and harsh environmental conditions. Additional experiences already being generated in further research areas and projects will be used for targeted lubricant development. Environmental aspects [5], standardised tests for lubricant evaluation [6], potential adaptable lubrication applications in forging [7] will be taken into account as well as directly transferable results [8, 9] or adaptable application technology [10].

The application of wear protective coatings on guiding components in hot strip mill has never been investigated until now. Nevertheless, wear of rolls is a big issue in the hot strip mill. In [11] coatings deposited by CVD or PACVD are addressed. A TiN coating enables better wear resistance of the parts which require lubrication. In [12], wear protective coatings were investigated such as PVD, high velocity oxy-fuel and dispersion coatings (electrolytic and electro less) to develop a new generation of wear and resistant thermal barriers. As coating requirements for work rolls are much higher than coatings for pinch rolls (regarding the roll load, stresses, etc.), the application for pinch roll coating has proven to be feasible.

The use of state-of-the-art coating application methods will be targeted to develop the best adherent protective wear coating. Based on the positive results obtained in [12-16], it is planned to study the dispersion coatings in this project. In general, the effectiveness of a wear protective coating can be described by characteristics like excellent bonding, suitable mechanical properties (strength and toughness), absence of flaws, thermal shock resistance and high temperature stability. To meet all these requirements, both a suitable deposition technology and an adequate coating composition must be combined. In [17] electro-less coatings showed less wear in comparison to electrolytic coatings.

To reduce the wear on pinch rolls, some industrial solutions exist. SMS Demag [18] developed a polishing equipment for the pinch rolls to prevent surface defects due to microparticles coming from the strip edges due to the contact with the entry guides and then getting stuck to the surface of pinch rolls. The device installed at the entry section of the pinch rolls ensures periodic cleaning and hence prevent the formation of pickups. Although the cleaning device developed by SMS is efficient to remove particles on pinch roll surface, ReduWearGuid project aimed at reducing wear due to contact between the strip and the pinch rolls. Therefore another wear protective solutions (lubricant and/or coating) are investigated in this project.

For that purpose, individual approaches will be developed to reduce mechanical and thermal wear in order to increase the life time of the pinch rolls, to improve the strip surface quality and reduce the production costs and downtimes.

## Description of the pinch rolls, surrounding and wear

The hot strip mill from TKSE has 3 pinch rolls pairs located before the 3 coilers (**Figure 1, Figure 2**). Their aim is to guide the strip into the coiler and to maintain its tension between the last finishing stand and the coiler. Once, the end of the strip comes out of the last finishing stand, it has to support the coiling process of the strip. Due to the high strip temperatures, the pinch roll must be cooled by water. The primary wear is abrasion caused by the contact between strip and roll intensified by particles from the side guides and strip edges. The high contact temperatures between strip and roll affect the mechanical properties of the roll material and decrease their strength. Due to this fact the upper and the lower pinch roll need to be reconditioned frequently.

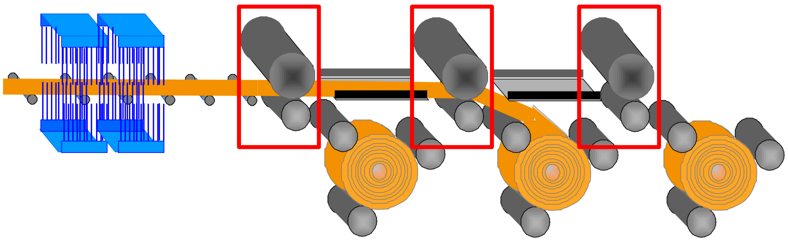


**Figure 1. Scheme of the 3 pinch rolls with their coilers**

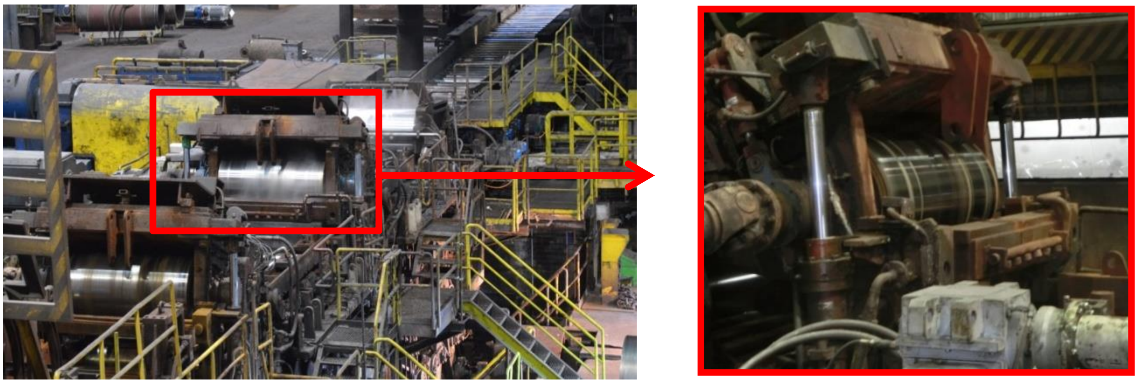


**Figure 2. Picture of the pinch rolls at the plant**

The rolls are not cylindrical and have a crown for a better guiding of the strip. The upper roll and the lower pinch rolls have respectively a crown of 1,5 mm and 3 mm on the diameter (**Figure 3**). In addition, as noticed in the scheme below, they are not aligned. It means that the lower pinch roll has higher contact with the strip than the upper pinch roll.

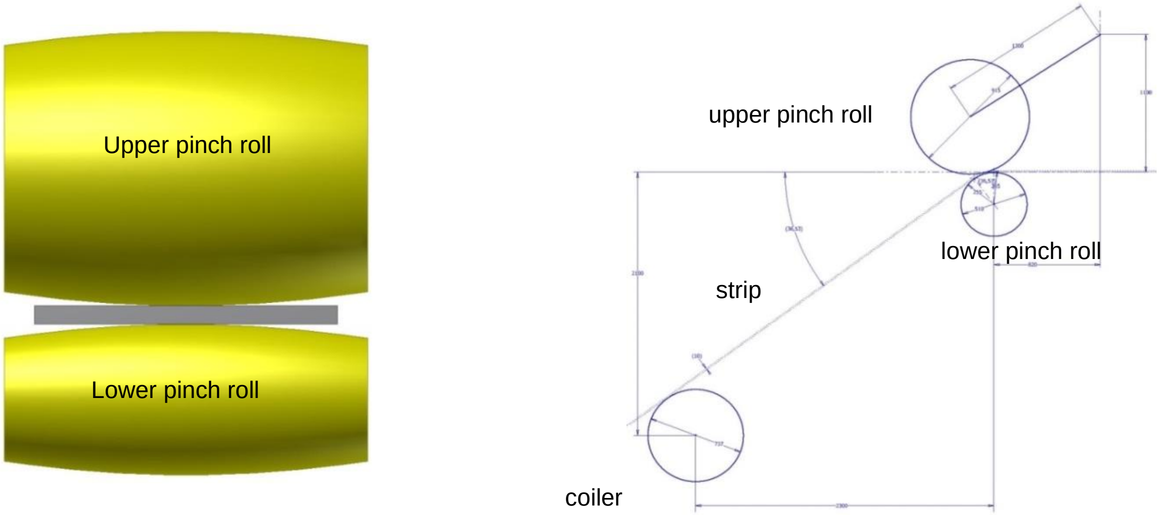


**Figure 3. Scheme of the pinch rolls**

In **Table 1**, general information about the pinch rolls are given. Both pinch rolls have a deposition welding on their surface having a thickness of about 15 mm. When the rolls are replaced during maintenance shift, they have to be grinded before to be again usable. The roughness of the pinch rolls was measured with a roughness device at three locations on a new and worn roll. In the middle of the roll, it was observed that the roughness decreased with the time (Ra from 1,6 µm up to 1 µm) and on the side, first a decreasing was noticed and then the roughness increased again (Ra decreased up to 0,7 µm and increased up to 2,2 µm).

**Table 1. General information about the pinch rolls**

| | **Pinch Rolls** | |
|---|---|---|
| | Upper Roll | Lower Roll |
| Roll Diameters | 895-910 mm | 490-505 mm |
| Roll Width | 1750 mm | 1750 mm |
| Weight | 5540 kg | 3033 kg |
| Roll Material | ST 52 | 42CrMo4V |
| Coating Material | deposition welding material | |
| Load | maxi 10 T | |
| Time (seconds) strip in contact with roll | 45-150 sec. (depends of strip dimensions) | |
| Differential speed of roll - strip | similar to the strip | |
| Cooling header | permanent cooling | |

At TKSE, they also have the possibility to measure the profile of both rolls (before and after removing of the rolls). This diameter profile along the length is really useful to observe the wear on the pinch rolls. The new pinch rolls are convex and after some time of utilisation, they become concave due to the abrasion between the strip and the rolls.
On the profile of two rolls measured, it was noticed that after about 15 000 coils, up to 3 mm can be lost on the diameter at the middle and up to 500 µm at the side for the upper roll. For the lower roll up to 4 mm can be lost on the diameter at the middle and 3 mm on the side. This concave profile has of course to be avoided because the diameter and the crown of the roll do not fit anymore. This leads to a worse guiding of the strip into the coiler (oscillating movement of the strip between driver and coiler). In addition, the placement of the strip is not acceptable and the surface of the strip can be affected.

## Technical solution

Key investigation in the project is to find the best applicable solution for the wear reduction. On pinch roll surface adhesive and abrasive wear is acting: to prevent wear of the pinch roll, two approaches are applicable: (i) lubrication and/or (ii) an innovative wear protective coating.

(i) Lubrication of the pinch rolls can reduce adhesive wear on the surface. Lubrication should act in a same way as for applied lubricants in hot rolling. Lubricant should generate a stable film on the pinch roll surface being exhausted as low as possible in the contact with the hot strip at the coiling unit (600 – 800 °C). Residue formation on the strip surface should be avoided to prevent undesired effects in subsequent processes and behaviour in the cooling circuit should be uncritical as well. Therefore low amounts of lubrication and the formation of thin film layer to guarantee excellent mobility to the pinch roll surface and less transferability to strip surface is targeted. Three water-based and one oil-based lubricants have been tested here.

(ii) Coating deposition techniques and coating material solutions will play a role when reducing the pinch roll wear. During the project, various wear protective coatings were studied and evaluated for the application on pinch roll using a combination of tribological tests to study abrasive, erosive and impact wear. A electrogalvanized hard Cr coating, electro-less Ni/P coating, a thermal spraying and two deposition welding material as well as the current deposition welding material have been investigated.

## Results from laboratory tests

### (i) Lubricants

The lubrication performance is in principle depending on two factors: quantity and quality. To evaluate the quantity of lubricant that will be applied, plate-out and wash-off tests have been performed (**Figure 4 left**). To evaluate the quality of the lubricant, lubrication tests have been performed (**Figure 4 right**). The plate speed can be varied between 1% (0.3 m/s) and 99% (11 m/s) of the plate transport speed. For wash-off, the same equipment is used but only water is applied instead of lubricant. This enables to evaluate the quantity of the oil that will remain on the roll, despite of water flushing. The weight difference between after and before spraying gives the plate-out value, which is defined as the quantity of oil per square meter remaining on the steel plate.
The coefficient of friction (COF) is the value obtained from the friction test, the wear rate is determined from weight loss of the plate. For the friction test a ball is used (point contact), for the wear test, a cylinder is used (line contact).
Two water-based lubricants presented very good lubrication performance. But the benchmark oil based product, showed slightly better performance than the water based lubricants. Some additional tests will be performed to determine which lubricant can be tested at the plant for the up-scaling.

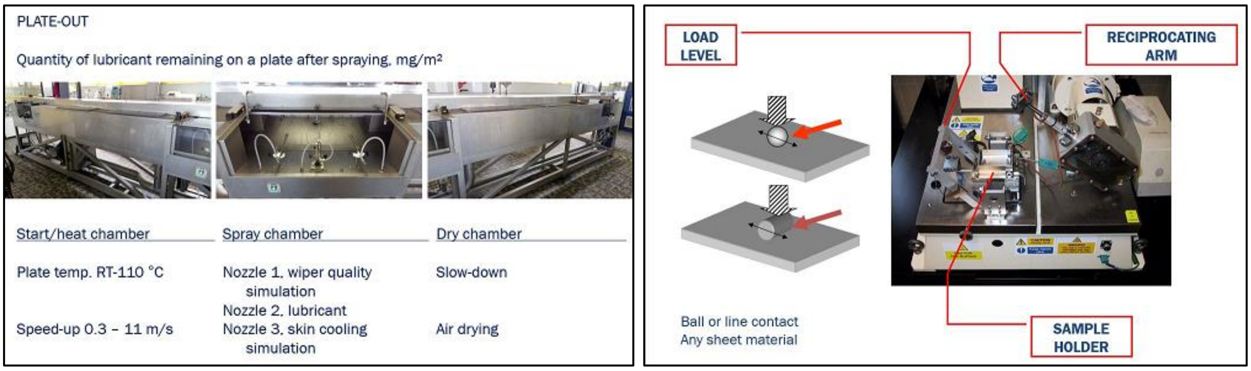


**Figure 4. Left: Plate-out and wash-off test equipment, Right: Lubrication test equipment**

### (ii) Wear resistant coatings

The various coatings were characterised in term of hardness, microstructures and wear tests. As the thicknesses of the coatings differ a lot (from 40 µm up to 15 mm), it was necessary to use a device with which it is possible to measure hardness in a really thin layer. A nanoindenter was used to carry out all the measurements. In all cases, a force of 500 mN has been used and ten measurements have been performed. The nanoindenter used has a Berkovich indenter with force control. An indentation hardness $H_{IT}$ is measured and revaluated in hardness in Vickers. The hardness was measured for all coatings either at the middle of the coatings (for Ni/P, hard Cr and thermal spraying coating) or at the last layer for deposition welding samples (**Table 2**).
In order to investigate the resistance to shock, spalling/peeling and the adhesion on coatings, impact tests have been performed (**Figure 5**). It enables to characterise the

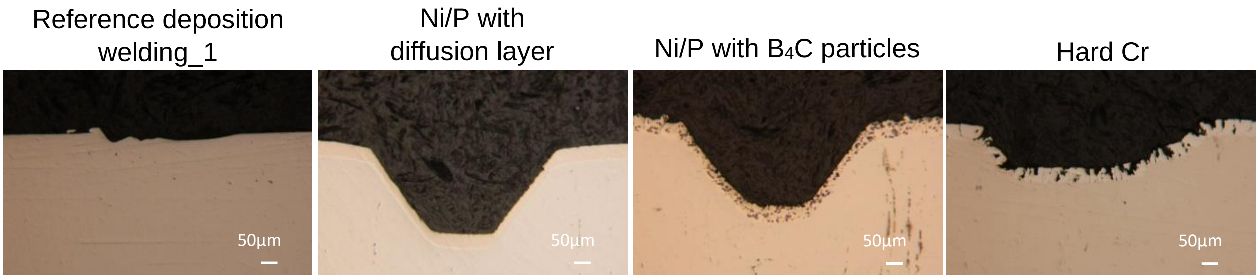
ductility of the coatings when charged with impact. The tube is 1,5 m high and the sharp chisel has a weight of 2 kg. In this test, we let drop the chisel on a sample (40 mm diameter, 20 mm high).

**Table 2. Hardness measured with a nanoindenter (F=500mN)**

| | Coating | Coating technique | Thickness | Hardness mesured (HV) |
|---|---|---|---|---|
| 1 | Deposition welding_1 (ref) | deposition welding | ~ 15 mm | 645 |
| 2 | Hard Cr | electro galvanising | 60 µm | 1019 |
| 3 | Ni/P + diffusion layer | electroless plating | 40 µm | 495 |
| 4 | Ni/P with $B_4C$ particles | electroless plating | 40 µm | 1071 |
| 5 | thermal spraying | HVOF | 150 µm | 1048 |
| 6 | Deposition welding_2 | deposition welding | ~ 12 mm | 581 |
| 7 | Deposition welding_3 | | ~ 12 mm | 931 |

**Figure 5. Impact test (chisel): Left: Scheme of the test, Middle: Picture of the tube, chisel and specimen holder, Right: Sample after impact test**

Cross sections of the samples of the impact location have been carried out (**Figure 6**). The following pictures show one particular section but it was quite representative of the all length of the groove.


Reference deposition welding_1 | Ni/P with diffusion layer | Ni/P with $B_4C$ particles | Hard Cr

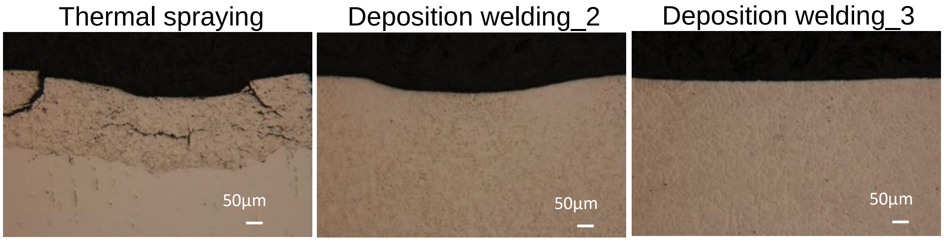

Thermal spraying | Deposition welding_2 | Deposition welding_3

**Figure 6. Cross sections of the samples after impact tests**

As expected, for the three deposition welding materials, as the thickness is really high, there is no influence of the substrate which has a lower hardness and therefore, the impact test is almost negligible and these kinds of materials will of course react well in case of impact of the strip with the pinch rolls.
Hard Cr coating and thermal spraying coating present similar depth after impact (in correlation with the similar hardness) but a lot of cracks are observed. It is much more brittle than the other coatings. These kinds of cracks are known for hard Cr coating but they would not lead to a complete destruction of the layer. The coating with Ni/P and diffusion layer presents the higher depth (which is related to the lower hardness). Finally the Ni/P with $B_4C$ particles presents also a quite high depth after impact test and some cracks in the coating. With the high hardness and the particles, it makes this coating also quite brittle.

In order to characterise the abrasion wear resistance of the coating, rubber wheel tests have been carried out (**Figure 7**). The rubber-wheel method is a standardised test procedure according to ASTM G 64 - 94, which is particularly suitable for testing brittle materials and various coatings. During the test, the specimen is pressed against a rubber wheel rotating at a predetermined circumferential speed by means of a weight for a specified period of time, while an abrasive substance (in our case: aluminium oxide $Al_2O_3$) is added to the gap between specimen and wheel. The analysis is done by weighing the sample before and after the test.

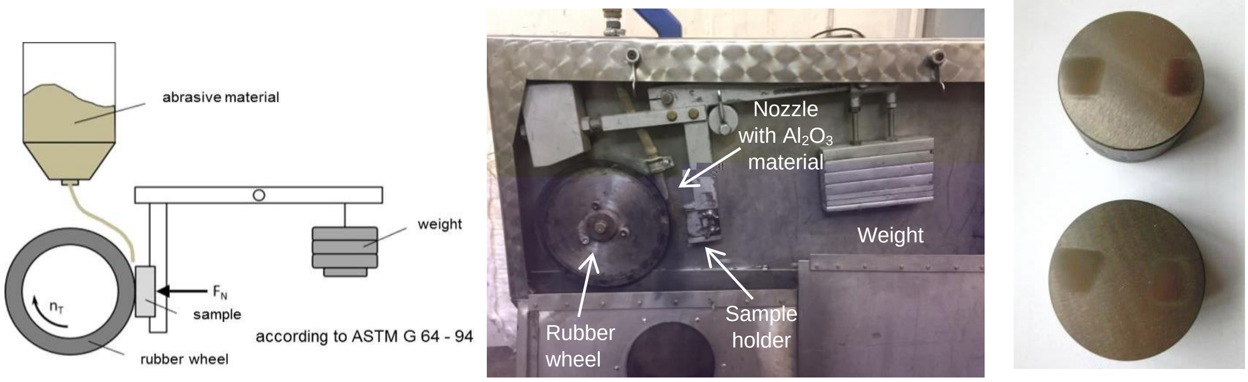


**Figure 7. Left: scheme of rubber wheel test, Middle: rubber wheel device, Right: samples after testing with two wear marks**

The same specimen geometry has been used (40 mm diameter and 20 mm high) as for the impact test. In order to compare all coatings, the following parameters were used:

- Test time: 1,5 min
- Velocity: 100 rpm (1,2 m/s)
- Rotation: 100 turns (corresponding to 161 m)

In order to get more information from the rubber wheel test, it was also possible to investigate the profile of the damaged surface. For this purpose a chromatic confocal system was used and in all cases the profile was measured on a width of 10,5 mm (**Figure 8**). The average depths are calculated for all profiles measured.

After weighing the samples, the results obtained from rubber wheel tests showed that the thermal spraying coating presented the best result in term of abrasion resistance. Ni/P with $B_4C$ particles and hard Cr coatings are the second candidates. All the deposition welding materials presented similar abrasion behaviour. On the profiles from damaged surface, same results were obtained: the thermal spraying coating presents the best result in term of abrasion.

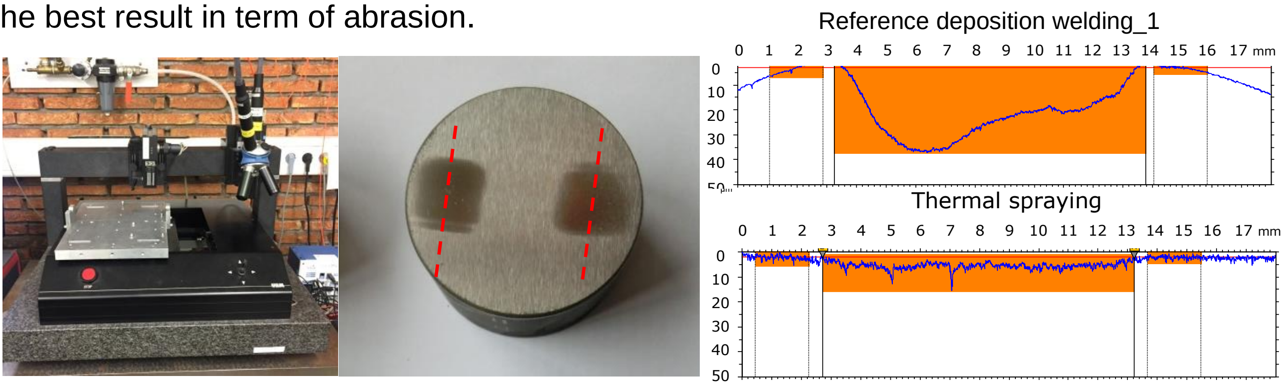


**Figure 8. Left: Chromatic confocal system to measure the profile after rubber wheel test, Middle: Example of lines on the wear marks where the profile of the damaged surface was measured, Right: Example of profiles of the damaged surface after rubber wheel test (1,5min, 150 rpm) for the reference and the thermal spraying coatings**

All coatings were compared in term of hardness, wear resistance, impact resistance and price. In regards with the results obtained, it was then decided to investigate more deeply the thermal spraying coating (best result for the abrasion resistance) as well as the deposition welding_3 (best result for the impact resistance and less expensive).

## First up-scaling at a laboratory scale

In order to characterise the wear resistance of the selected lubricants and coatings in a way close to the industrial process, it is intended to carry out some trials at the two-rolls hot test bench [19]. An overview of the device is given in **Figure 9 left**. The two rolls are driven with a maximum velocity of 900 turns/min and they can be driven with a different velocity. The bottom cylinder is simulating the lower pinch roll and the top cylinder the steel strip. The top cylinder can be heated up to 1000°C with an induction oven while the bottom cylinder is heated only by contact (**Figure 9 right**).

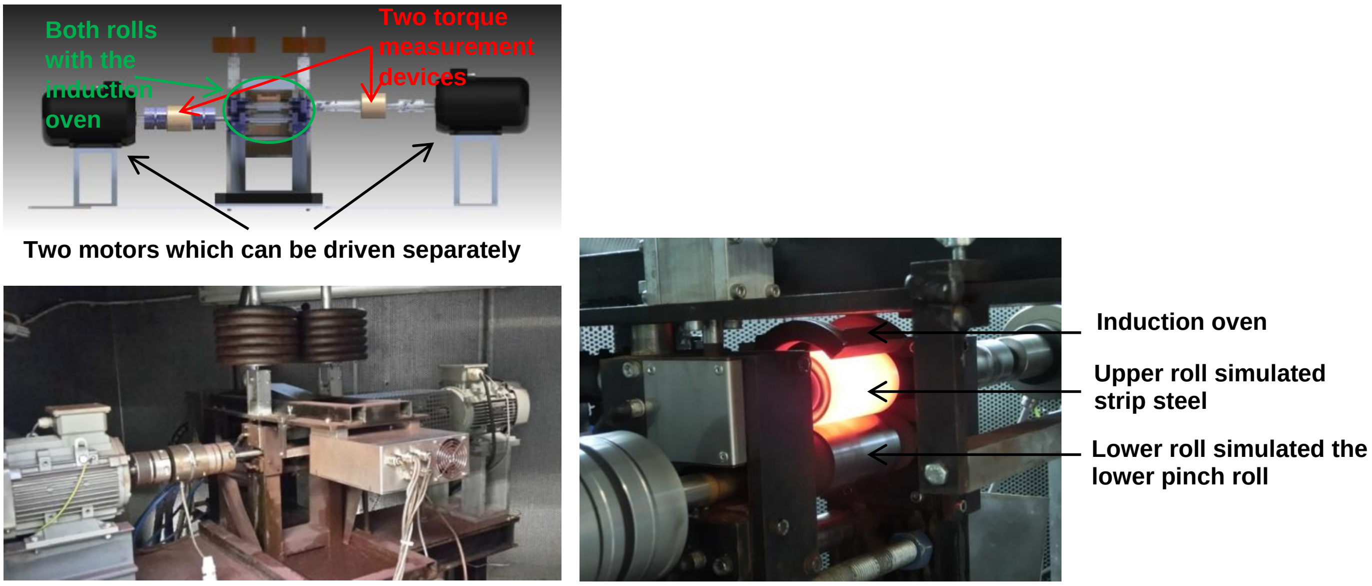


**Figure 9. Left: Schematic and picture of the 2-rolls hot test bench, Right: Two-rolls hot test (the upper roll is heating by an induction oven while the lower one is heated by contact)**

The different parameters influencing wear (temperature, cooling, lubricant flow rate, type of nozzles, etc.) were studied through the roughness evolution, the surface inspection and the torque reduction with the different lubricants.

In the coiler area, the strip at TKSE plant has a temperature varying from 50 to 900 °C but in average a temperature of 620/660 °C is observed. As it is unfortunately not possible to weld a lower roll with the current deposition welding material (diameter too small for the deposition welding techniques), it was decided to choose another material having really similar mechanical properties (1.2343 steel). The upper roll simulates a strip often produced at TKSE: a St52-steel. Using similar parameters than at TKSE, the upper roll was inductive heated up to 650 °C, a rotation velocity of 302 rpm for the both rolls and a cooling of the rolls (flow rate = 0,7 l/min) were used as test parameters for the two-rolls hot test bench. Three lubricants have been tested (two water-based and one oil-based) and a roll with a thermal spraying coating will be tested within the next weeks. In order to characterise the wear state and the lubricity performance, the weight loss, the roughness, the diameter reduction and the torque reduction after spraying have been estimated. Regarding the wear (weight loss and diameter reduction), the water-based lubricant 2 presented the best results (2 g loss in comparison with 3-3,2 g for the two other lubricants, 32 µm diameter reduction in comparison with 58-60 µm) and this lubricant presented similar torque reduction than the oil product (**Figure 10**). This water-based as well as the oil-based lubricants will be tested at the pinch roll during the up-scaling process.

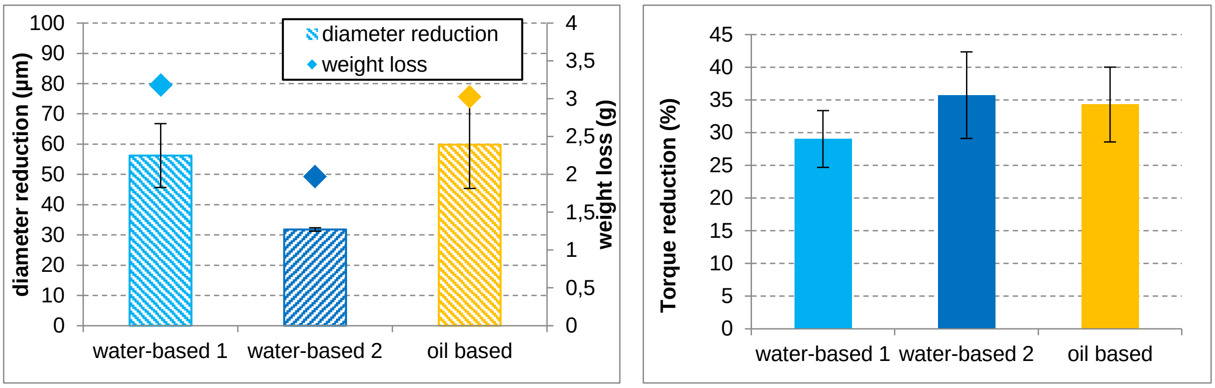


**Figure 10. Results after trials at the two-rolls hot test bench. Left: diameter reduction and weight loss of the lower roll, right: torque reduction after lubricant spraying**

## Conclusion and perspective

In the scope of a research project, it has been found that a thermal spraying coating or another deposition welding material are 2 relevant wear resistance coatings for an application on the pinch roll. The using of a water-based or an oil-based lubricants could also be a promising approach to reduce the wear on the pinch rolls. The different solutions will be investigated directly at the plant within the next months and the best candidate will then be installed / used in the future.

## Acknowledgment

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