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Tribological Aspects of Advanced Roll Material in Cold Rolling of Stainless Steel

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Abstract**—**Vancron 40, a nitrided powder metallurgical tool Steel, is used in cold work applications where the predominant failure mechanisms are adhesive wear or galling. Typical applications of Vancron 40 are among others fine blanking, cold extrusion, deep drawing and cold work rolls for cluster mills. Vancron 40 positive results for cold work rolls for cluster mills and as a tool for some severe metal forming process makes it competitive compared to other type of work rolls that require higher precision, among others in cold rolling of thin stainless steel, which required high surface finish quality. In this project, three roll materials for cold rolling of stainless steel strip was examined, Vancron 40, Narva 12B (a high-carbon, high-chromium tool steel alloyed with tungsten) and Supra 3 (a Chromium-molybdenum tungsten-vanadium alloyed high speed steel). The purpose of this project was to study the depth profiles of the ironed stainless steel strips, emergence of galling and to study the lubrication performance used by steel industries. Laboratory experiments were conducted to examine scratch of the strip, galling and surface roughness of the roll materials under severe tribological conditions. The critical sliding length for onset of galling was estimated for stainless steel with four different lubricants. Laboratory experiments result of performance evaluation of resistance capability of rolls toward adhesive wear under severe conditions for low and high reductions. Vancron 40 in combination with cold rolling lubricant gave good surface quality, prevents galling of metal surfaces and good bearing capacity.

Keywords**—**Adhesive wear, Cold rolling, Lubricant, Stainless steel, Surface finish, Vancron 40.

I. Introduction

THIS project is part of a larger project that include design of in-line wear and temperature profile for strip mills, the study of roll wear prediction model for strip and plate mills and the evaluation of roll materials with regard to roll wear, surface quality and galling.

Roll materials were evaluated experimentally in laboratory and in pilot rolling mill. This work is the results of the experimental part. The types and properties of the tool materials, the experimental procedures and the results were presented in this paper.

The aim of this work was to study three proposed tool materials, supposed to use as a roll materials in the cold rolling of stainless steel strip. Two works roll types; Vancron 40 [2], [3] and Supra 3 are manufactured by means of powder metallurgy and Narva 12B is produced by means of conventional casting technologies. The tool material Vancron 40 is still under development for using in cold rolling of stainless steel.

The study was conducted with respect to roll wear, surface quality and galling (adhesive wear). As galling or “pick-up”, is a result of heavy friction forces due to the sliding contact and the adhesive nature of the work material, the galling mechanism is closely related to adhesive wear. Tool materials characteristics, physical and chemical properties and recommended heat-treating process are described. Concerning tool material Supra 3 which was used currently as work roll in industrial operation, was used as reference material.

Tool materials were to experimentally examine under severe tribological conditions. Scratch test [4] of the strip, galling, surface roughness and lubrication performance used by steel industries was investigated.

The investigation and development of tool material Vancron 40 was based on the previous research experiences, where Vancron 40 give very positive results for cold work rolls for cluster mills and it also used as a tool for some severe metal forming process, like fine blanking. Considering those advantages and its good grindability makes it competitive compared to other type of work rolls that require higher precision, among others in cold rolling of thin stainless steel, which required high surface finish quality.

II. Adhesive Wear and Galling

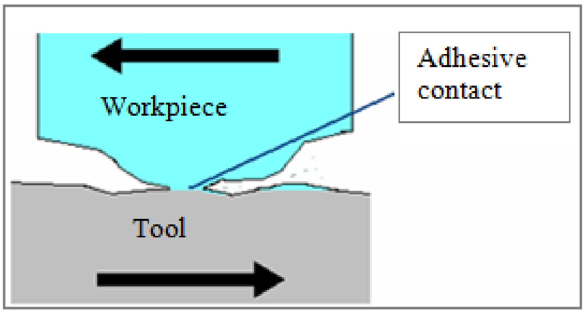

Fig. 1 Schematic illustration of adhesive wear

In cold rolling applications of stainless steels and mild steels, galling and adhesive wear are often the dominating tooling problems [5]. Galling is considered as an adhesive wear caused by macroscopic transfer of material between metallic surfaces during transverse sliding.

The process and contact can be compared to cold welding or friction welding as shown in the Fig. 1. Galling, as a very sever adhesive wear can also referred to as 'pick-up' or

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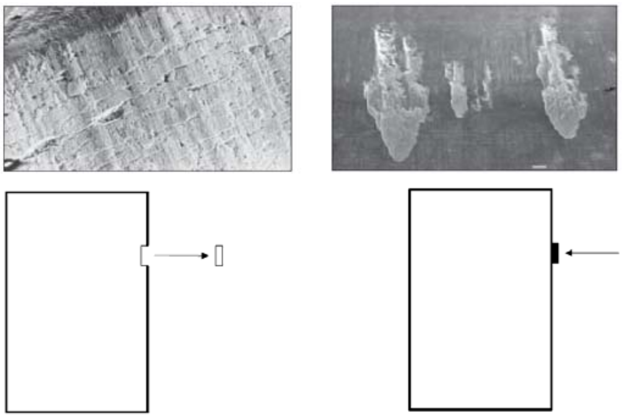
'transfer'. Fig. 2 shows simplified illustrations of Adhesive wear and Galling.



(a) (b)

Fig. 2 (a) Adhesive wear, pieces pulled out of the tool surface by the work material, (b) Galling, pieces transferred to the tool surface from the work material

III. Tool Materials

Vancron 40, with its surface coating gives suitable surface topography and a friction condition during rolling without the demand to introduce a real surface coating with anti-galling properties [2], [3]. In cold rolling applications of stainless steels and mild steels, galling and adhesive wear are often the dominating tooling problems and Vancron 40 is believed to offers the possibilities of eliminating the both time- and cost-consuming surface coatings. This is achieved in the manufacturing process of Vancron 40 by introducing an extra nitride operation.

Narva 12B is a roll type from a high-carbon, high-chromium tool steel alloyed with tungsten, and it characterized by:

- Highest wear resistance
- High compressive strength
- High surface hardness after hardening
- Good through-hardening properties
- Good stability in hardening
- Good resistance to tempering-back

NARVA 12B is used successfully in cold rolling applications of stainless steels because of its wear resistance, high compressive strength and high surface hardness after hardening. As tool material Narva 12B has gained widespread acceptance as steel with exceptional wear resistance, suitable for long-life tooling with low repair and maintenance costs, for maximum production economy.

SUPRA 3 which is used as roll grade reference in this project is a high alloyed powder metallurgical high speed steel corresponding to the material AISI M3:2 [6] with a very good abrasive wear resistance in combination with compressive strength. It is suitable for demanding cold work applications like blanking of harder materials like carbon steel or cold rolled strips and cutting tools. The machinability and grinding are superior than for conventional high speed steel and so is the dimensional stability after heat treatment.

A. Chemical Composition of the Tool Materials

Chemical compositions of the three tool materials (steel grades) are shown in Table I. As shown in the table, Vancron 40 has been designed to have a dense distribution of small vanadium rich nitro carbides and a few molybdenum rich carbides in martensitic matrix. Vancron 40, as a nitride powder tool steel, is "surface coated" and considered that coating is already integrated into the finished tool material. That principle gives suitable surface topography and a friction condition during rolling without the demand to introduce a real surface coating with anti-galling properties.

TABLE I
Chemical Compositions of the Tool Materials Vancron 40, NARVA 12B and SUPRA 3

Roll grade	Steel grade	Type of metallurgy	Chemical compositions (weight %)							
			% C	% N	% Si	% Mn	% Cr	% Mo	% W	% V
Vancron 40	Vancron 40	Powder metallurgy	1.10	1.80	0.50	0.40	4.50	3.20	3.70	8.50
Narva 12B	Narva 12B	Conventional	2.05	-	0.30	0.80	12.70	-	1.10	-
Supra 3	Supra 3	Powder metallurgy	1.28	-	0.50	0.30	4.20	5.00	6.40	3.10

IV. Experiments

Laboratory experiments were carried out with Strip Reduction Test (SRT) [7], [8], experimental method developed by DTU-Technical University of Denmark. This experimental method was used before in different research works, among others:

- In evaluation of materials response to a specific type of wear
- Screening materials, lubricants, and coatings

The objectives of examining tool materials in SRT were to examine scratch of the strip, galling and surface roughness of the tool materials under severe tribological conditions.

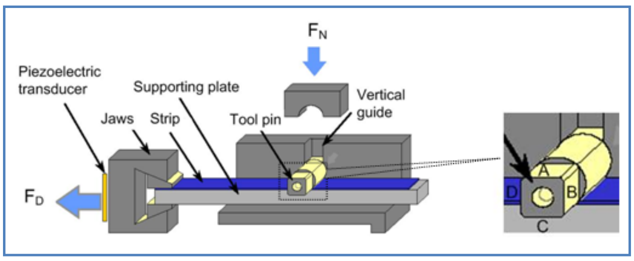


Fig. 3 The principles of the Strip Reduction Test experimental deice

The critical sliding length for onset of galling in SRT was estimated for stainless steel with four different industrial lubricants. The principles of the experimental deice is shown in Fig. 3.

As shown in Fig. 3, the metal strip work piece is reduced in thickness by a non-rotating cylindrical tool held in place by vertical guides. The tool is fixed with a defined displacement into the strip and the strip is then reduced in thickness by pulling the strip and support plate as shown in Fig. 3. The normal pressure and pulling speed is held constant throughout the test but the temperature will increase due to friction and plastic deformation. Depending on the tribological properties of the chosen lubricant, tool material, tool hardness; the tool might experience cold welding of work piece material to the tool with subsequent scratching of the strip surface. This phenomenon of cold welding of work piece material to the tool and scratching of the subsequent work piece surface is known as galling.

To study the lubrication performance, the same tool was tested with four different lubricants **(**lubricants A, B, C and D).

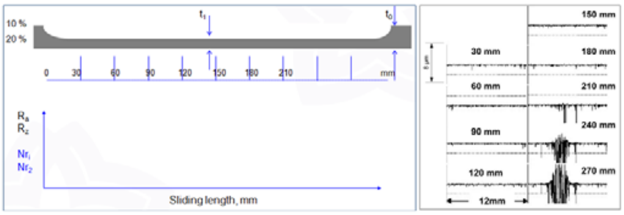


Fig. 4 Typical measurement of roughness profiles across the strip width at regular intervals, Nr_i : Number of valleys deeper than 1.0 µm, Nr_2 : Number of valleys deeper than 2.0 µm

The principle of the measurements is shown in Fig. 4. 10% and 20% reductions and seven sliding lengths (sliding length 30 mm to 210 mm, with a range of 30 mm) for each strip with four types of lubricants were obtained. The reason of taking several sliding lengths is to help analyzing initiation and progress of galling in the sliding length range. Unfortunately, due to severe process conditions and not using an extremely high load bearing capacity, such as chlorinated paraffin oil, the initiation and progress of galling was observed in the early sliding length range 10 and 30 mm. The reason for that is that the industrial recommended lubricants didn't allow using of chlorinated paraffin oil in their rolling operations. Despite those challenges, the experiments of "the strip reduction test" are believed to give some indication about galling. Galling is typically a progressive effect that when initiated will escalate fast due to local pick-up on the tool surface. The roughness of the strips is then measured across the strip width, i.e. orthogonal to the drawing direction hereby registering any scratches due to galling. The number of scratches deeper than 1µm (N_{ri}) and deeper than 2 µm ($N_{ri,2}$) compared to the average height is counted automatically in the software and is saved along with several other roughness parameters. These parameters can then be plotted versus the sliding length giving a clear idea of the performance of the different lubricants. The progress of galling is shown in Fig. 4.

The following experimental conditions were applied: Work piece/strip

- Material: Stainless steel, 304
- Dimensions: 0.7x15x500 mm

Lubricants (four types)

A: Mineral oil with additives of fatty acids, high viscosity
B: Mineral oil with Ester and EP additives, lower viscosity than A
C: Mineral oil with Ester and EP additives, lower viscosity than A and B (C has another type of concentration than A and B)
D: Mineral oil with additives of fatty acids, high viscosity

Process parameters

- Reduction, *r*: 10-20 %
- Temperature: Room temperature, 20 degrees C
- Average sliding speed: 80 mm/s
- Surface roughness of tool materials, R_a: 20 µm
- Two hydraulic cylinders with a max. force of 5 kN each
- The max. sliding length: about 300 mm

V. Results

Evaluation of average surface roughness, R_a, for reductions 10% and 20% and four proposed lubricants and three tool materials, Supra 3, Vancron 40 and Narva 12B is shown Fig. 5. As shown in the figure, Vancron 40 in combination with lubricant C (mineral oil with Ester and EP additives, lower viscosity) gave very low R_a for both low and high reductions. Lubricant C is a mineral oil with Ester and EP additives and has lower viscosity. Lubricates A, B and D show similar tendency for all three tool materials; with lower R_a for lower reduction (10 %) and higher R_a for higher reduction (20%). Similar results were also obtained for R_z.

The slope of R_a curve for Vancron 40 (V40) and reference material Supra 3 (ASP23) for the higher reduction, 20% is shown in the Fig. 6. The slope of a curve shows the bearing capacity of the lubricants, where the slope of a curve of Vancron 40 is lower (dashed lines) and higher for the dotted lines (ASP23).

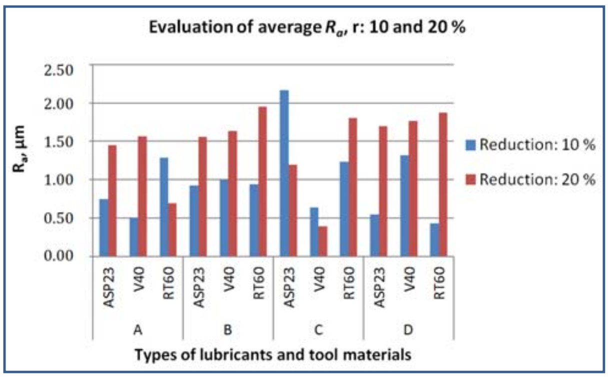


Fig. 5 Evaluation of average R_a for reduction, r= 10 and 20 % for four types of lubricants and three tool materials, Vancron 40 (V40), Narva 12B (RT60) and Supra 3 (ASP23)

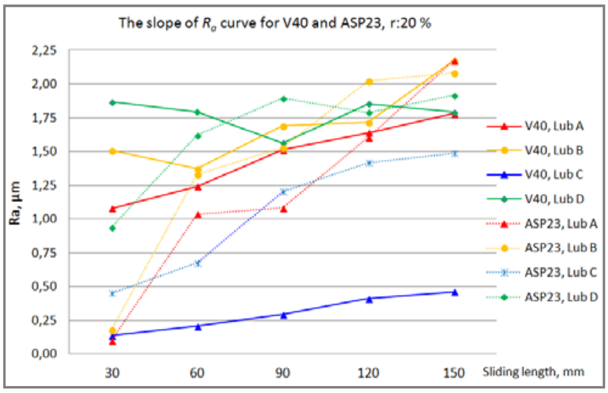


Fig. 6 The slope of R_a curve of Vancron 40 (V40) and Supra 3 (ASP23) for reduction 20 % with four different lubricants. Sliding length 30 mm to 150 mm

Evaluation of galling; N_{r2}, that is the number of valleys deeper than the limited value for galling for reduction 10 % and 20 % is showing in Fig. 7. Accepted N_{r2} depends on the lubrication and material. Due to severe tribological conditions, appropriate lubricants used for evaluation by means of "strip reduction test" were chlorinated paraffin.

Fig. 7 shows the result of using lubricants A, B, C and D for the three roll materials. As shown in Fig. 7, N_{r2} of Vancron 40 remains lower with the use of lubricants B, C and D. The results also show that N_{r2} of Vancron 40 is not affected much with increasing of reduction from 10 % to 20 %, which shows that the influence of reduction is not restricted in case of Vancron 40, spec. in using lubricants C and D.

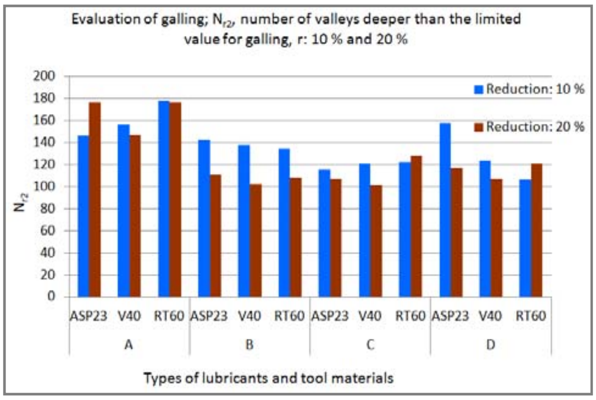


Fig. 7 Evaluation of galling, N_{r2}, for reductions, r= 10 % and 20 % and lubricants A, B, C and D. Vancron 40 (V40), Narva 12B (RT60) and Supra 3 (ASP23)

VI. Conclusions

Despite severe tribological conditions, roll materials were evaluated with respect to roll wear, surface quality and galling. Strip reduction test (scratch test) gave some sort of performance evaluation, specially the resistance capability of rolls toward adhesive wear under severe conditions for low and high reductions.

In case of Vancron 40, the progressive effect and the escalation of local pick-up was very little in comparison to Narva 12B and Supra 3. The reason can be that Vancron 40 properties of "surface coating" which is already integrated into the finished tooling material. As the used lubricants missing effective EP-additives the dispersion of adequate film between the sliding and rolling contact areas is believed to be low or none. Due to that reason some scratching errors were occurred. The self coating properties of Vancron 40 ("integrated surface coating") in combination with Lubricant C gave good surface quality, prevents galling of metal surfaces and good bearing capacity.

Acknowledgments

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