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Transfer of surface texture from silicon nitride rolls to stainless steel wire in cold-rolling

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Abstract

A set of cold-rolling experiments with ceramic rolls was carried out using facilities for the production of profiled steel wire. Based on the experiments, the strength of sintered silicon nitride was found sufficient for allowing cold-rolling of austenitic stainless steel wire. The wear rate of the silicon nitride rolls in the tests was low. Metal was transferred from the wire to the rolling tracks of the ceramic rolls. The surface texture of the rolls was reproduced on the rolled product.

Keywords: Silicon nitride; Cold-rolling; Wire rolling; Surface transfer; Wear; Surface roughness; Texture

1. Introduction

Rolling is a three-dimensional plastic flow process used for the forming of metallic sheet material and profiles. In rolling, a work piece material is brought into a gap between two rolls. Due to the reduction of the material thickness in the work zone, the work piece material is accelerated first, before the neutral plane of the work zone, to the surface velocity of the rolls, then to a velocity higher than the surface velocity of the rolls, as seen in Fig. 1. When a wire material is rolled, this spreads laterally in the work zone during the thickness reduction, and the rolling process results in a cross-section that is lower and wider and has an area that is smaller than that of the work piece material [1].

The surface quality of cold-rolled sheet and wire materials is normally of great importance, as the rolled surface often forms a functional surface of an end product. The surface quality of the cold-rolled product is sensitive to the surface quality of the rolls, and for this reason particular emphasis is put on the roll surface finish. For certain purposes, textured rolls that give a desired surface structure to the cold-rolled material are used [2,3]. In addition to the roll surface modifications, alterations in the lubrication, velocity and degree of reduction, for instance, provide means to control the surface quality of the cold-rolled product [1–5].

For more than a decade, hybrid ball bearings composed of silicon nitride ceramic balls and steel races have been successfully used particularly in high-speed applications [6–8]. One of the benefits of the use of silicon nitride ceramic balls is the diminished need for lubricating oil, owing to the good surface quality that can be achieved on a silicon nitride surface by polishing. Similarly, silicon nitride rolls that operate against steel camshafts in engines have been successful [9]. Experience with hybrid ball bearings and ceramic cam followers has shown that silicon nitride is beneficial in rolling contacts, which has created interest in the use of this ceramic material in metal rolling applications.

A question frequently raised when ceramic materials for machine elements and tools are discussed is the issue of the strength and reliability of these non-metallic materials. One of the central approaches of the present study was to evaluate the performance and reliability of silicon nitride rolls in actual steel-rolling processes. The other approaches comprised tribological aspects of cold-rolling with ceramic rolls, including the transfer of the roll surface texture (surface profile waviness and surface roughness) onto the work piece material. In order to facilitate the evaluation, a set of cold-rolling experiments was carried

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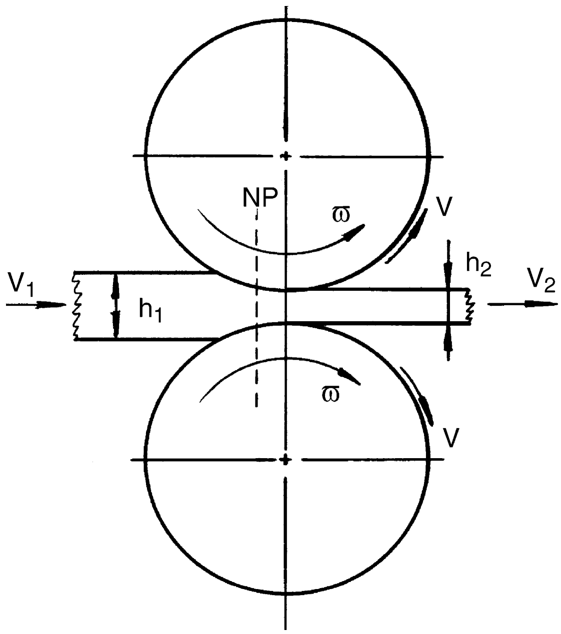

Fig. 1. Schematic presentation of the cold-rolling of wire; h_1 is the entry thickness and h_2 the exit thickness of the wire. Due to cross-section area reduction, the wire exit velocity v_2 is higher than the entry velocity v_1. The line NP represents the neutral plane, at which the contact pressure between roll and wire reaches a maximum and the roll and wire surfaces have the same velocity v. Wire tension at entry or exit zones can move the neutral plane, but was not applied in the present tests.

out using production facilities for cold-rolling of profiled steel wire. In the following, the preparations and procedures for the experiments and the post-test investigations are presented and discussed.

2. Experimental

2.1. Equipment

The experiments were carried out using a cold-rolling mill at Haldex Garphyttan Wire AB. The rolling mill had four consecutive rolling passes, each with a two-high roll configuration, the last one of which accommodated the ceramic rolls. During the rolling procedure, rolling oil from a circuit with filtration was sprayed from nozzles onto the rolls and wire. An overview of the rolling mill is shown in Fig. 2 and a detailed view of the first ceramic roll pair before the tests is shown in Fig. 3.

Fig. 2. The cold-rolling mill used for the present experiments. The final rolling pass is at the right end of the mill.

Fig. 3. Exit zone of the final rolling pass with ceramic rolls 1 and 2 and two oil nozzles.

Taylor–Hobson Form Talysurf diamond stylus equipment was used for measuring the surface roughness of the ceramic roll surfaces, the wire surfaces and the rolling tracks on the ceramic rolls. All the surface roughness measurements were done perpendicularly to the rolling direction of the wire and roll samples.

Of the measurement results used in the present study, the surface roughness parameter Ra represents the arithmetic mean surface roughness [10], as an average value for five individual measurements of at least 5×0.25 mm length each. The Ra value, however, carries no information about the shape of the surface profile.

The Rsk value expresses the surface profile skewness as a mean value for five individual measurements of at least 5×0.25 mm length each; for $Rsk > 0$ the surface profile is dominated by peaks while for $Rsk < 0$ the surface profile is dominated by valleys.

The surface roughness parameter Rp indicates the highest peak and Rv the deepest valley of the surface profile within a measurement. The Rp and Rv values given in the tables are mean values for five individual measurements of at least 5×0.25 mm length each.

All surface roughness values in the present work are based on filtered profiles from measurements using standard cut-off lengths (λ_c) of 0.25 or 0.8 mm. The values for the wire samples are presented with reference to the upper and lower surfaces, of which the former were formed against upper rolls and the latter against lower rolls of the rolling equipment.

2.2. Materials

Four ceramic rolls, mounted on individual steel support shafts, were used in the experiments, in sets of two rolls each. The ceramic materials for the rolls, with a hollow cylinder shape, had been manufactured by cold isostatic pressing and gas pressure sintering (GPS) from Si_3N_4 powder with a few percent of binder and sintering additives. The as-sintered hollow cylinders had been ground on their inner and outer surfaces, and mounted with a conical press fit on steel shafts. When tightly mounted on the shafts, the outer cylindrical surfaces of the