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The Wear Analysis of Steel Yarn Guide in Ring Spinning Frame

Abstract
This paper presents the results of our investigations into the wear of steel guides by yarn blends. The guides were made from steel 50SiCr4 which was hardened and tempered to a hardness value of 400 HB. Two kinds of blends, the 80% viscose/20% cotton and 30% polyester/70% wool yarn blends were used. We attempt to explain the wearing model of the tribologic couple composed of a steel guide and yarn. The analysis of the surface condition and EDS spectrums of the surface layer at the place of the yarn friction, as well as the steel microstructure at the cross-section which is perpendicular to the groove furrowed by the yarn, permits us to conclude that wear by abrasion is of decisive importance.

Key words: *wear model, steel wear, spinning machine wear, yarn guide wear.*

Introduction

In ring spinning frames, some parts directly adjoin the yarn or roving. Steel yarn guides are commonly used. The guide's working surface should meet at least three requirements:
- it should be characterised by a low friction coefficient to the yarn, mainly dependent on the stereometric structure of the surface (SGP 3D) resulting from the kind of treatment it receives;
- it should not generate an electrostatic charge and thus charge the yarn; and
- it should be sufficiently resistant to wear and accidental impacts.

Until now the steel yarn guides in the ring spinning frames manufactured in the Bielsko-Biała Factory of Textile Machines, among many others, have been made of spring steel grade 50SiCr4, which was hardened and tempered to a hardness value of 400 HB in order to provide suitable resistance against wear, as well as a sufficient working lifetime. However, observations made in the industry have proved that their lifetime is still unsatisfactory, especially regarding the production of yarn blends in mixtures of 30-55% polyester and 70-45% wool. The aim of this work is to estimate the wear in industrial conditions of a guide's eyelet made from spring steel 50SiCr4 after hardening and tempering to 400 HB, and especially to try and explain the wearing model of a tribologic pair which consists of a steel guide and yarn.

Evaluating wear of the guides in cooperation with yarn in industrial conditions

The wear of the yarn guides was investigated using the metric method on PG-7A ring spinning frames used for balloonless spinning in the Merilana woollen industry company in Bielsko-Biała. The technological schema of the PG-7A ring spinning frame is presented in Figure 1.

Two series (140 pieces each) of yarn guides made from steel 50SiCr4 and hardened & tempered to 400 HB were used for our observations. The shape and dimensions of the guide made from a drawn rod Ø4h9 is presented in Figure 2. The subject of processing (on the same ring spinning frames) consisted of the following two yarn blends: 80% viscose / 20% cotton, and 30% polyester / 70% wool. The thicknesses of the rod inside the guide's eyelet were measured with a ZKM01-250C microscope (Carl Zeiss Jena) before installation in the spinning unit, and after subsequent use after 2,760; 3,780, 4,750, 5,820, 6,700, 7,700, 8,670 and 10,400 hours.

The wear value Δz in mm (Figure 5.b) was evaluated as the difference between the executed measurements. In Figure 3, we present a histogram of yarn-guide wear for those guides which worked in cooperation with a 80% viscose /

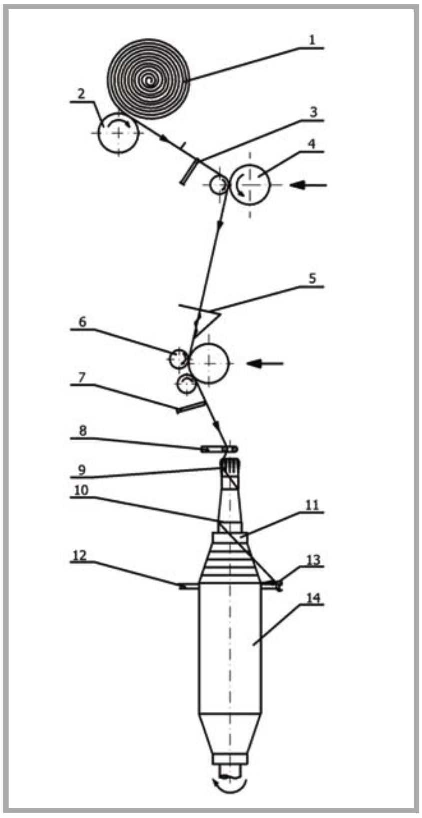

Figure 1. *Technological schema of PG-7A ring spinning frame: 1 – roving, 2 – lap roller, 3 – roving guide, 4 – feeding roller, 5 – false twist spiral, 6 – delivery rollers, 7 – suction cleaner, 8 – yarn guide, 9 – thimble, 10 – collapse balloon spindle, 11- bobbin, 12 - ring, 13 – traveller, 14 – yarn package.*

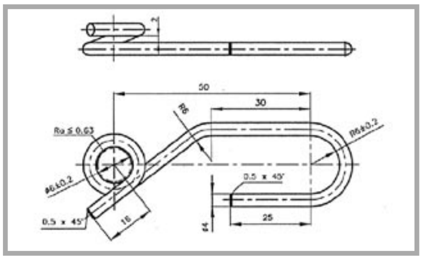

Figure 2. *Shape and dimensions of yarn guide made of steel 50SiCr4 used in ring spinning frames .*

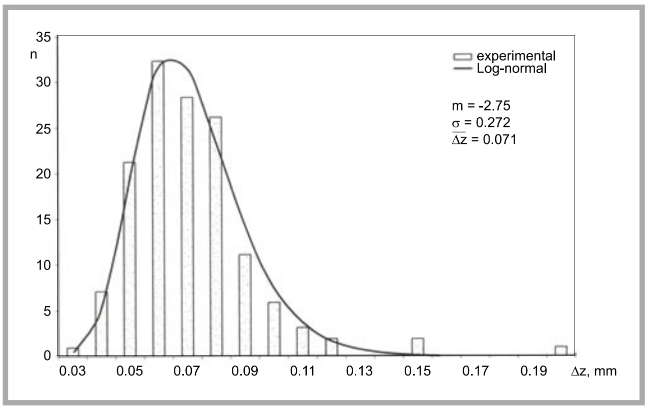

Figure 3. Histogram of yarn-guide wear for a yarn-guide made of steel 50SiCr4 which worked in cooperation with a 80% viscose / 20% wool yarn blend.

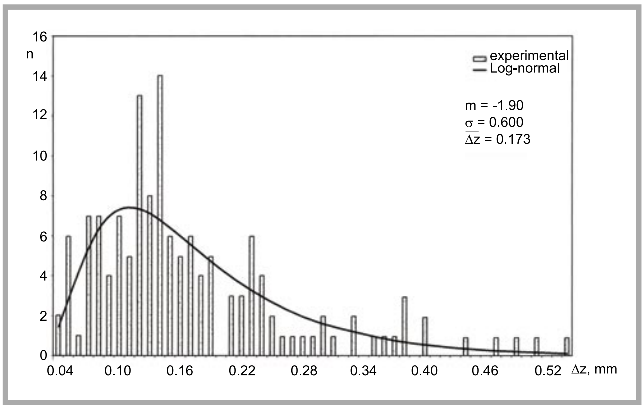

Figure 4. Histogram of yarn-guide wear for a yarn-guide made of steel 50SiCr4 which worked in cooperation with a 30% polyester / 70% wool yarn blend.

20% wool yarn blend, whereas Figure 4 shows a histogram of yarn-guide wear which worked in cooperation with a 30% polyester / 70% wool yarn blend.

The histograms of yarn guide wear were described with the following theoretical distributions: normal, exponential, Weibull and log-normal. The best fit was obtained using log-normal distribution. The hypothesis on the convergence of empirical and theoretical distribution was verified by means of a chi-square test at a significance level of 0.05. It follows from observations and measurements that the average yarn-guide wear of a guide working in cooperation with the 30% polyester / 70% wool yarn blend was about 2.5 times greater than that which worked with the 80% viscose / 20% cotton yarn blend. For this reason, further consideration was limited to the wear of the yarn guide working with the 30% polyester / 70% wool yarn blend.

The increase in average wear of almost 2.5 times in the case of the 30% polyester / 70% wool yarn blend, compared to the 80% viscose / 20% cotton yarn blend, can be explained by the higher values of the tensions in the polyester / wool yarn mixture behind the friction barrier, which were caused by the 30-40% higher speed of the transported yarn. According to the rheological theory of friction, the value of the friction coefficient is the linear function of the yarn thread speed, which results in a progressive increase in the values of the yarn tensions behind the friction barrier [1]. Other investigations [2] show that the forces in the yarn increase more intensely (in other words, they are progressive) with the increase in speed. The yarn's structure probably also has an influence on the guide wear. The stream of fibres of the polyester / wool mixture acts more destructively on the surface layer of the steel guide than the stream of the viscose / cotton mixture. This is for two reasons: firstly, being a component of the yarn blend, wool additionally contains in itself vestigial particles such as grass, tree bark, straw and dust grains which intensify the friction process and the wear; secondly, wool fibres possess hulls (husky structures) on their surface, which can also negatively influence the guide's surface during cycles of repeated pressure from the yarn on the guide for long periods of time.

The wear model of the tribologic couple: steel guide – yarn

Figure 5 presents a guide eyelet hardened and tempered to 400 HB before being installed in the spinning device, and after exploitation for about 8,000 hours with a 30% polyester / 70% wool yarn blend. In Figure 6, the shape of the groove eroded inside the eyelet surface is observed at a magnification of 40×.

Figure 7 shows the yarn drawing course from the delivery rollers of the mechanism the guide, and then the socket (bit) and neck of the spindle lining for PG-7A balloon-less ring-spinning frames.

The tension of the 30% polyester / 70% wool yarn blend at the entry to the yarn guide was measured with a C-1386 probe (Rothschild) with a measurement range of 0 - 0.981 N at three positions of the ring bench: 1 – the base of the yarn package, 2 – the middle of the yarn package, and 3 – the vertex of the yarn package. We took the type and thickness of the yarn, the turns of the outlet rollers, the weight of travellers, the turns of spindle n = 9,500 rpm, and the distance from the yarn guide to the upper surface (forehead) of the thimble (9 mm) as constant parameters of spinning during the tension measurements.

The maximum value of yarn tension was measured at the end of the yarn package forming, i.e. at the yarn package vertex. To calculate the maximum pressure force at the entrance of the guide originating from the yarn tension, the maximum tension at the yarn entrance was assumed as $F_o \sim 30$ cN. It follows from the construc-

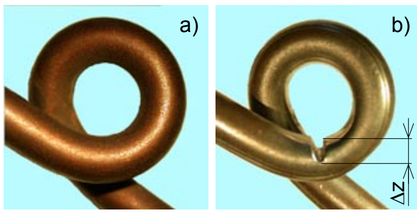

Figure 5. Guide eyelet hardened and tempered to 400 HB: a - before installation in the spinning device; b - after 8,000 hours of use (magnification 3×).

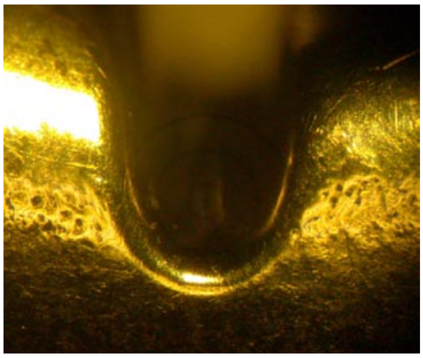

Figure 6. The groove view situated inside the yarn eyelet after 8,000 hours of use (magnification 40×).

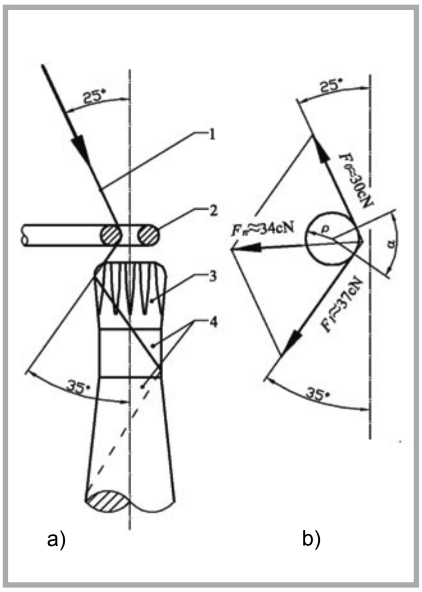

***Figure 7.** The yarn guide position in relation to the spindle axis and the temporary position of the yarn at input and output from the guide; a) - roving course from delivery rollers to the guide, and then the thimble and spindle lining neck (1 – yarn, 2 – yarn guide, 3 – thimble, 4 - spindle lining neck); b) – yarn tension at input and output from the guide and the yarn pressure force exerted at the guide.*

tional data of the PG-7A ring-spinning frames for balloon-less spinning that the temporary value of the angle between the yarn proceeding from the delivery rollers to the guide and the spindle axis is about 25°. However, the maximum angle value between the yarn outlet from the guide to the thimble and the spindle axis is about

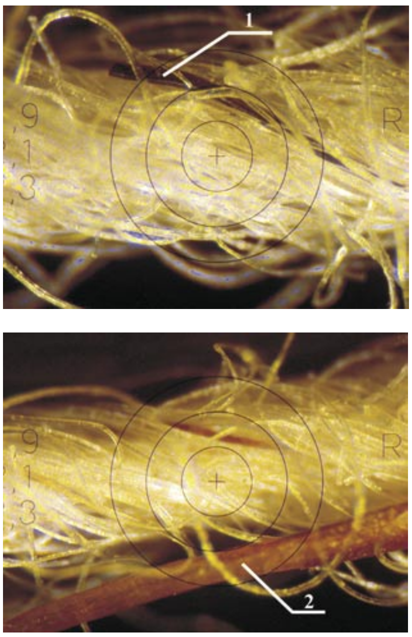

***Figure 8.** The view of yarn containing foreign elements: 1 – grass, 2 - straw, magnification 100×.*

35°. The yarn tension behind the friction barrier (behind the guide) was evaluated from Euler's formula:

$$F_1 = F_o \cdot e^{\mu\alpha} \qquad (1)$$

where:

- μ – the kinetic coefficient of friction between the yarn and the guide's surface (measured as μ = 0.20 [3]);
- F_o – the tension before the friction barrier,
- α – the angle of wrap of the guide by yarn (in our case α = 60°).

The maximum temporary pressure value of the yarn to the guide was evaluated from the law of cosines, and amounts to about F_n ~ 34 cN (Figure 7.b).

While testing the 30% polyester/70% wool yarn blend, we discovered that it caused intensive eyelet wear (Figure 6), because wool very often contains small foreign particles such as grass, tree bark, straw and quite often grains of dust (Figures 8.a and 8.b). The fibre stream was guided at a speed of v_w ≈ 30 m/min (at a rotary speed of the spindles of 9,500 rpm) with maximum tension up to about 30 cN and variable amplitude.

The character of the fibre arrangement in the 30% polyester / 70% wool yarn blend and the surface structure of a single wool fibre are presented in photos taken with a Jeol-J7 electron microscope (Figures 9.a and 9.b). Figure 9.b shows the typical husky structure of a single fibre of wool.

Figure 10 shows a photograph of the steel 50SiCr4's surface after hardening and tempering inside and outside the eyelet, and Figure 11 shows the EDS spectrums assessed. Observations of the steel and yarn surfaces coming into contact were made using the Jeol-J7 electron scanning microscope, while the steel surface layer was examined with a JCXA 733 X-ray analyser.

Observations of the eyelet's surface at the place of wear with the unaided eye and at a magnification of 5× (not shown) creates the illusion that the surface is smooth and shining (having a metallic sheen), whereas in photos of this surface taken at 400× (as shown in Figure 10.a) scratches in the same direction as the yarn movement are visible. In contrast, the surface outside the eyelet (Figure 10.b) is rough and covered by a layer composed of complex oxides.

The chemical analysis of the surface layer of the eyelet bottom which was cut by the yarn did not reveal any oxygen content (Figure 11).

It can be assumed that the process of surface layer destruction is very likely to have consisted in the separation of oxide layers, caused by oxygen adsorption in the yarn friction areas (oxidation wear).

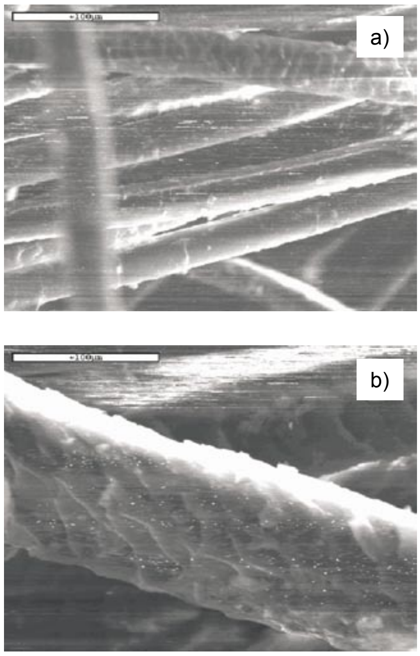

***Figure 9.** 30% polyester / 70% wool yarn blend: a) – character of the fibre arrangement, magnification 400×, b) – the surface's husky structure of a single wool fibre, magnification 1000×.*

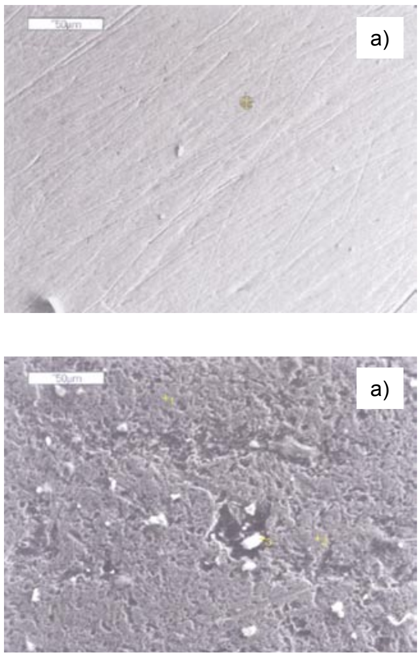

***Figure 10.** Photo of steel 50SiCr4 surface after hardening and tempering, (magnification. ×400): a) – surface in stitch of guide in the place of wear, b) – surface outside the stitch.*

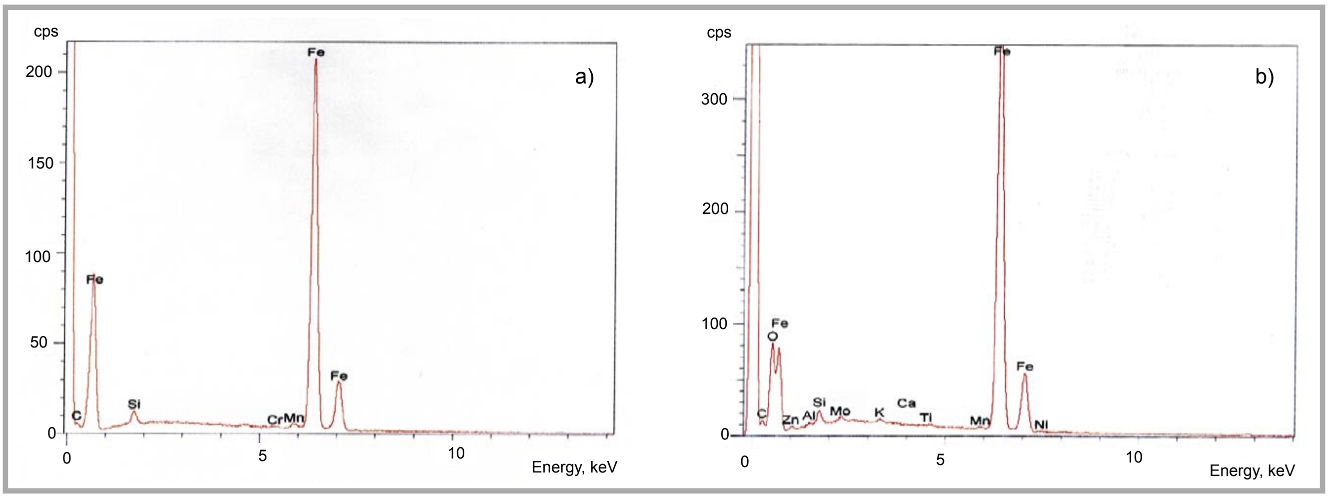

Figure 11. *EDS spectrum obtained for the surface of the guides investigated made of steel 50SiCr4 after hardening and tempering: a – surface of the guide eyelet at the place of wear, b – surface outside the guide eyelet.*

Additionally, the guide's cross-section at the place of the groove formation was investigated with a microscope. The material's structure in the subsurface groove layer (Figure 12.a) and in the guide core were compared. There is no essential difference between the structure of the steel in the subsurface zone at the place of wear (the groove has a depth of 0.7 mm) or in the guide core, i.e. at a depth of about 2 mm from the surface.

The most likely argument is that the material loss in the guide's eyelet is caused by the material's micro-volume separation, caused by the friction of solid particles such as grass, tree bark, straw and dust) situated inside the fibres' stream and shifting together with it at a speed of $v_W = 20$ - 30 m/min. The particles included in the fibre stream are pressed down at different strengths onto the guide surface as the result of different yarn pressures caused by the yarn's cyclical entry and exit from the thimble notches, and the changeable position of the spindle axis during rotary movement. It can be accepted, by analogy to polishing with canvas or abrasive paper, that the solid particles work as micro-blades. In the authors' opinion, it is very likely that during yarn friction at the guide surface, abrasive wear is of predominant significance, the basis for which is presented in the following publications [4 - 6]. Two factors have a decisive influence on the intensity of this wear: yarn tension, which directly influences the pressure value in the place where the fibre stream contacts the eyelet, and the speed of the yarn. The polyester fibres contained inside the treated yarn, which are characterised by considerably higher strength than wool, enable the spinning process to continue with higher efficiency. This increase in efficiency is directly connected to the higher speed of the yarn stream. As mentioned previously, the yarn speed increases directly in proportion with the tension values, and indirectly with the higher value of the yarn pressure on the guide.

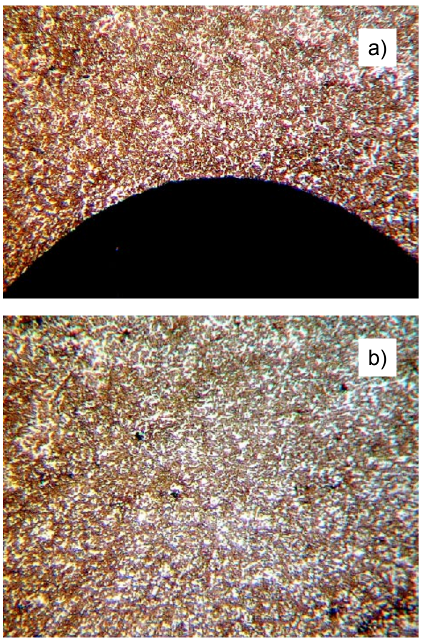

Figure 12. *The internal guide's microstructure (steel grade 50SiCr) observed at the cross-section normal to the furrowed groove: a) – in the subsurface zone of the groove furrowed by yarn, magnification 200×; b) – in the core of the guide, magnification 200×.*

Summary

On the basis of our investigations and their analysis, we can assume that the abrasive process is very likely to have a fundamental influence on the wear of the yarn guide made of steel 50SiCr4.

A complex explanation of the wear model of the tribologic pair composed of a steel guide and yarn would require further investigation of the condition of the surface layer at the place of yarn friction. Also, temperature measurements of the surface during friction when spinning at variable yarn shifting speeds would be useful.

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