Navel – Surface Characteristics as the Decisive Factor for Superior Quality in Rotor Spinning

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Mechanical, thermal as well as tribological (issues related to friction, wear and lubrication) characteristics of navels made of alumina ceramics are gaining in importance. The grain structure of polycrystalline ceramics determines the attainable surface quality. In turn surface quality results in surface characteristics of navels that are directly linked to their capability in terms of productivity, service life and quality of textile.

Provided that the opening roller as well as rotor have been carefully selected, the navel is the spinning component that plays a key role with regard to ensuring the economics of rotor spinning. Moreover, the navel is the element that determines to a significant degree favourable characteristics of the yarns in further processing.

Introduction

For more than five years Broell Corporation has dedicated itself to the development, evaluation and production of navel systems made of advanced ceramics. Since 1999 a complete manufacturing facility for the production of textile machinery components made of advanced ceramics has been installed. We see that our many years of experience in ceramics combined with our expertise in textile technology have guaranteed the development of innovative system components. Thus yarn manufacturers benefit not only from ‚plug and spin solutions' but also from ‚plug and win solutions'.

Since 1884 Broell has provided customised solutions to its end users. Direct marketing of the stand-alone K-generation of navels (the classical Rieter KK and the Schlafhorst KN series, but with improved ceramics) and the new Spirit series, entailing now 8 formerly nonexistent models, meets the needs of yarn developers and spinners.

In light of the present technological maturity of yarn spinning machines, spinning components have increasingly become the economic battleground.

After a shake out in the 70's and 80's which determined the technologies in the marketplace the 90's were marked by miniaturisation combined with increasing manufacturing precision. Today the fiber/surface interaction is increasingly analysed microscopically. As a result tribology issues have to be resolved in order to achieve further enhancements. In the near future the equipment of essential components with ‚intelligence' will further widen capabilities [1]. In combination with textile technology this opens up a new crossdisciplinary field of activity of high potential.

In rotor spinning, apart from the classic criteria, the OE-spinning components determine the economics and yarn quality. Navels as the key element for guiding the yarn and inserting false twist merit the level of attention devoted to them. This becomes even more obvious considering the fact that the OE- spinning technique without further innovations would reach its technological processing limits at around 175,000 rpm.

An increase in performance is limited by the mechanical and thermal stress that the fiber raw material can withstand, as well as the fiber characteristics. Neither the opening roller nor rotor constitute stress limits. The navel/yarn system experiences the highest mechanical and thermal stresses.

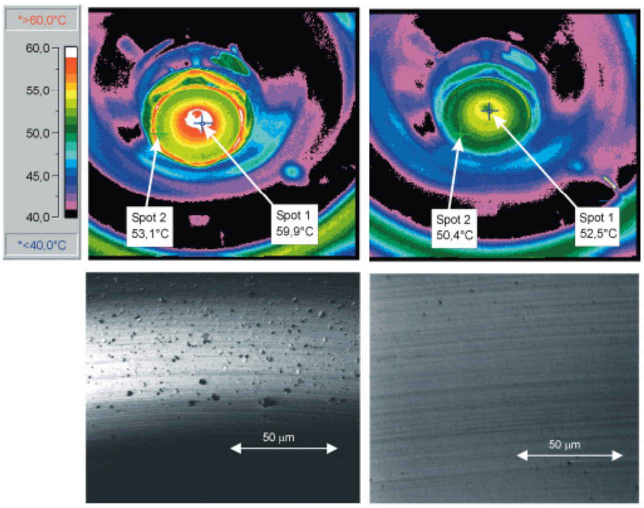

Figure 1 shows correlation between friction temperature and surface of ceramic navels

Comparison between ceramics and steel

Ceramics are made of finely dispersed raw materials that, once put into the desired shape, are exposed to a high temperature treatment. Diffusion processes and chemical reactions that take place during this treatment will determine their characteristics. Ceramics react with brittle fracture behaviour after initial almost linear elastic behaviour [2].

Dense in technical terms, pure polycrystalline $A1_20_3$ is free of pores (theor. Dens. 3.985 gr/cm^3) and exhibits a thermal conductivity of around 33 W/mK and a strength of HV0.05 = 2500 N/mm^2. A ductile highly coated steel (density of 7.85 g/cm^3) has a thermal conductivity of around 15 W/mK, whereas the strength of high quality nitride steel is HV0.05 = 800 – 1100 N/mm^2 [3,4]. Strength characteristics correlate with resistance to wear. However, the quoted thermal conductivity broadly contradicts observed practices! Experience teaches us that steel navels are preferable when it comes to the treatment of thermally sensitive fibers due to better fiber and yarn protection characteristics. However, this does not necessarily have to be the case as shown in the following.

While developing navels and surfaces at Broell three rules that are universally applicable to all fiber materials have been formulated. These rules have been established by microscopic analysis and the condition over time of distinct surface markings of navels, independent of the working material, and these rules are as follows:

1.) The fiber / yarn is unforgiving. Any previous damage will have a negative impact on its subsequent processing.
2.) There are two options: either the textile will shape the navel surface or the navel surface will shape the textile.
3.) Every imperfection found on the navel surface limits the potential of the fiber, yarns and spinning process in terms of quality and productivity.

Steel navels – irrespective of good or bad initial surface structure- will be permanently ‚polished' by the yarn. This results from the inherent properties of steel. As a consequence the replacement of a steel navel is due to unacceptable deformation of the polished surface by waves (material displacement). There is a strong departure from the initial geometry due to wear. Wash-out effects and distortion of the groove design happens – under the prerequisite that grooves exist. This goes hand in hand with a loss in spinning stability and deterioration in yarn quality.

A mirror-like surface is imperative for navels made of ceramics. Navel smoothening due to the spinning process does not occur when alumina is used – exactly the opposite effect will take place if the material structure does not possess optimal wear resistance and if it does not allow any flexibility. In that case it leads to either mono or polycrystallinity and thus to eruption of sharp-edged grains. Ceramic experts describe this phenomenon as intercrystalline wear. The underlying reason is the high- frequency periodic oscillation behaviour of the yarn on the navel surface. Frequencies greater than 100 kHz are no exception – even for navels without grooves. The higher the frequency the higher are the forces acting on the navel surface (‚whip impact'). This explains the untimely development of clearly visible chatter marks on steel navels caused by plastic grain deformation.

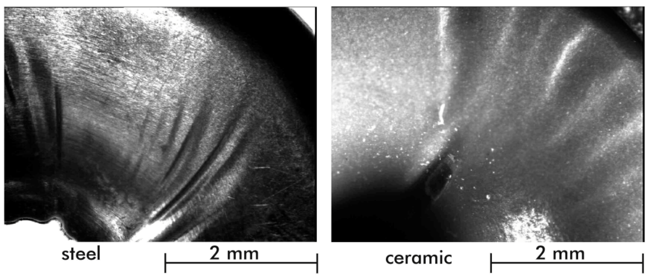

Figure 2 shows a comparison of worn out steel navel vs. worn out ceramic navel

Compared to steel, navels made of ceramics are brittle hard. However, they have the ability to exhibit equivalent favourable tribological behaviour towards yarn as steel navels, given the right material structure and surface.

Requirements for navels from a tribology point of view

Requirements in terms of tribology can be grouped under three headings:

1.) long service life: fit for constant productivity
2.) fiber and yarn protection: fit for yarn quality and problem-free further processing
3.) yarn and material look: fit for fashion and quality standards

In practice, an increase in productivity always depends on a decrease in yarn breaks and an increase in delivery speed. The latter can be achieved by reducing yarn twist. However, in this case the navel needs a pronounced false twist effect. Due to the potential loss of elongation, an increase in rotor speed can only be achieved by a reduction in (dynamical) yarn tension – therefore the geometric characteristics of navel and rotors are more decisive.

It is commonly understood that man-made fibers are more aggressive towards the surface of navels than clean cotton. However, if cotton contains trash and sand, faster wear can be observed. The effect of the navel surface on man-made fibers is clearly greater than that on cotton fibers which are covered by a wax and pectin layer. Furthermore consistent dyeing is a challenge for chemical as well as for natural fibers caused by excessive thermodynamical stress at the navels.

Figure 3 shows emerging speed of yarn on surface of navel.

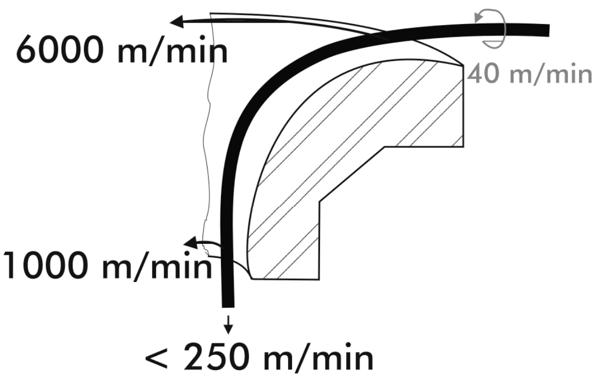

Figure 3 shows emerging speed of yarn on surface of navel.

At a rotor speed of 120,000 rpm the yarn moves and rotates more than 2,000 times per second on the navel surface. The resultant speed of about 6,000 meters per minute, measured at the very edge of the navel, makes it clear that we are dealing with a speed an order of magnitude higher than is reached by twisted yarns anywhere else in the textile world. Therefore much attention has to be paid to the choice of the right spin finish alone.

A wise saying known in the world of textile tribology states that it is always favourable to provide a rough textile surface with a smooth (processing) surface (and vice versa!). Spun staple fibers are classified as rough textiles in this case. As a consequence a brightly polished navel surface is imperative in order to reduce friction. However, polishing does not help in reducing textile damaging pores as demonstrated by the following figure:

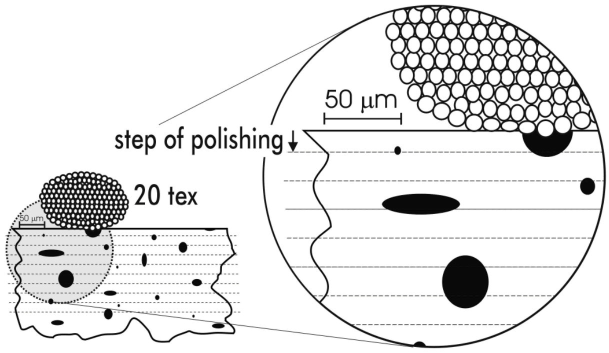

Figure 4: Polishing does not eliminate pores on ceramic surfaces.

A reduction in the number of pores requires compaction of the material structure. The material density should be as close as possible to the theoretical maximum achievable density (point of reference: > 99.5% of theoretical maximum density). Only a slight decrease in ceramic density from 99.5% to 99.0% of the theoretical maximum density can provoke an increase in friction from υ = 0.2 to υ = 0.7. Through effects explained in the following discussion, measured yarn values will suffer considerably.

Where does wear on navels take place?

Seen in yarn running direction, wear on a navel becomes first visible on the top left of the grooves and on the groove entrance. Hence, this is where the highest mechanical yarn impulses occur. Another zone, which is also highly loaded in grooveless navels, can be found between about 45 and 60° to the doffing direction. It is here that the highest contact pressure and relative speed and therefore highest thermodynamic stresses prevail.

How do navels wear out?

If a high quality navel is distinguished by an impressive surface luster then worn out navels of average quality ceramic can be identified by their dull surface caused by an increasing number of pores. Investigations of actual practice revealed that, depending on quality demands of spinning, an increase in number of pores by a factor of 2 to 50 compared to the initial state is tolerated before a navel is replaced. The reason is the disintegration of the ceramic grains. The disintegration of grains at (sharp-edged) pores is even more drastic. As a consequence holes measuring 50 to 100 um emerge very quickly which can easily be detected on the navel surface by a practictioner with the help of a pin.

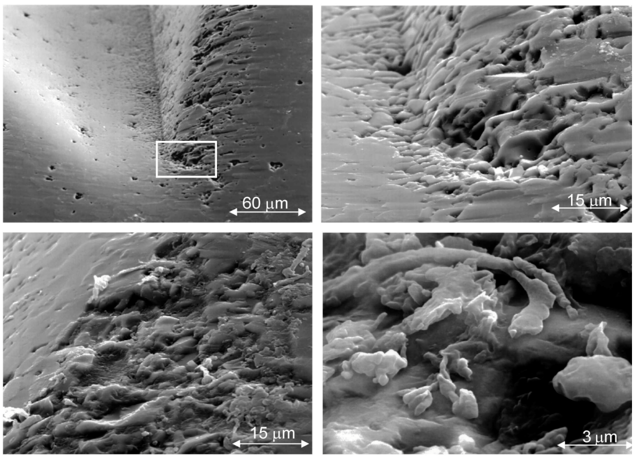

Figure 5: Fiber cemetery as a result of intercrystalline wear at the groove entry (high staff-values)

The pore is the root of all evil

The purity of the alumina, the maximum density achieved and the surface quality, shape the properties of navels. The purity of monodisperse alumina should amount to a minimum of 99.7%. Alumina of that purity is of white to ivory colour. The higher the level of material purity, the so much higher is the

- intercrystalline strength and overall strength
- hardness
- thermal conductivity (alumina of 99.7% purity still attains merely 85% of its potential thermal conductivity)
- corrosion resistance

The last criterion plays a particularly important role for processing of man-made fibers. For alumina with a low level of purity the silicate substances act as "cement between grains". However, these glass phase declines due to chemical-mechanical attacks. Moreover the glass phase acts as a thermal insulator around each grain.

The density serves as an indicator for achieved quality of surface. Every discrepancy to a smaller value in ceramic density results from defects of grain structure. In the best case, pores are closed and spread evenly throughout the alumina . However, during polishing of the surface these closed pores will turn into open pores. Today the specification for final density lies at 3.92 gr/cm^3. An increase in final density from 3.92 to 3.96 gr/cm^3 reduces the number of defects by 300 to 400%! In other words, yarn has to face about 5,000 defects of 50 um diameter on the convex surface for a classical four notch navel and will face 1,000 pores for a navel at 3.96 gr/cm^3 density.

Once a pore approaches the dimensions of the fiber or even the yarn it is called a microscopic defect. On the one hand a (closed) pore represents a heat insulator thus reducing thermal conductivity by deviating from the ideal density . On the other hand (open) pores of such dimension are the origin of wear. Thirdly, the pore on the surface acts as a depot in this case. Abraded fiber constituents conglomerate thereby increasing friction on the yarn which in the end can make spinning impossible – in contrast to mechanical engineering (where pores filled with lubricant can be of a big benefit in reducing friction).

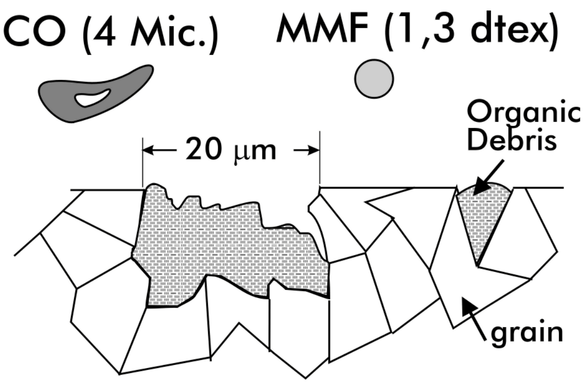

Figure 6: A pore in the ceramic structure and respective fibre dimensions

Ceramic wear vs. textile characteristics

The life cycle of a navel varies according to stresses imposed on it as well as to the requirements of the spinner or downstream processor. Usually the life cycle of navels is 6 to 48 months. Extreme examples just underpin demanding quality standards. The rotor yarn is located in the region of the navel for 5 to 15 turns of the rotor . Independent of delivery speed a yarn touches every 1 to 2 mm the same region of the navel surface or touches the same potential defects. If the type of wear is purely transcrystalline (smooth wear through the grain) the navel will act as favourably as a steel navel. If wear is intercrystalline, microfractures will appear around sharp-edged grain boundaries – resulting in at least a significant increase in Staff (fly) values as well as mostly a loss in yarn tenacity.

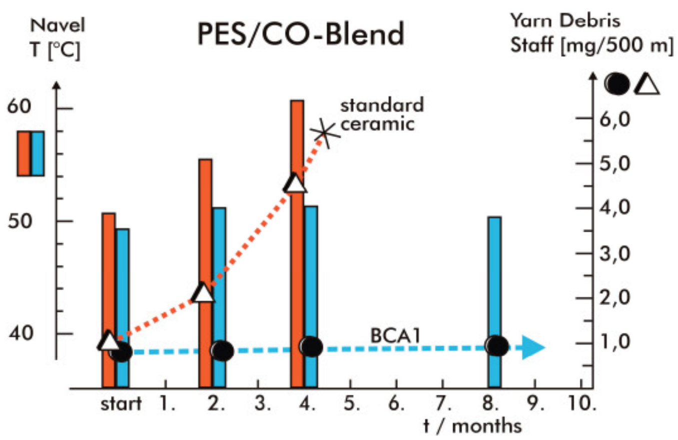

Figure 7: Time dependence of Staff (fly) values as indicator for wear of the navel

Variations from position to position can be limited by a more precise positioning between metal holder and ceramic navel. This is where another development by Broell Corporation comes in: the ceramic press fit, as it guarantees the highest possible centering not only between ceramic navel and holder but simultaneously between face plate and rotor.
As a positive secondary effect press fit enhances thermal conductivity of ceramics and holder. Moreover press fit does not need any thermal isolating glue thereby eliminating the risk of glue residue sticking on the navel or the flying out of the navel into the rotor itself. Finally, at the same time the procedure of pressing acts as a quality gate as flawed ceramics do not pass this stage.

Summary and conclusion

The differences between alumina ceramics are as diverse as they are for steel. Number and size of pores detected on a surface of a navel indicate the level of achieved density of the alumina structure. The purity of the ceramic determines the strength of grain boundaries. The smaller the grain the more ductile is the ceramic. Taking these parameters into account from the early stages of the development process is the best way to achieve high production navels for OE spinning: navels that are characterized by high resistance to wear combined with favourable behaviour in terms of development of wear, a lower yarn friction while simultaneously providing higher thermal conductivity. By this means proven increases in productivity of 5 – 15 % are attainable. Top economic efficiency with microfibers, from high productivity of OE yarns, is achievable by applying such a highly advanced navel design together with attaining the highest possible rotation speed of rotors when processing man-made fibers.
In the context of "nanosizing" more positive characteristics of ceramics can be revealed and benefited from in the future.

Sources

[1] Sonntag, E.: Developments in Spinning – the Tribological Approach, Tribology 2000 -Plus, 12th Int. Trib.-Colloquium, Jan.11-13th, 2000, Vol.3, 1565-1569 as well as www.broell.com
[2] Gräfen, H.: Lexikon der Werkstofftechnik, VDI-Verlag, Düsseldorf 1991
[3] Rohde, M.; Schulz,B.: The Effect of the Exposure to Different Irradiation Sources on the Thermal Conductivity of Al203, Journal Nuclear Materials 173 (1990), S.289
[4] Touloukian, Y.: Thermophysical Properties of Matter, Vol.2, Plenum Press, N.Y., 1970
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