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Analysis of Hardness Variations In Radial and Longitudinal Directions of Bobbins In Step Precision Winding

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ABSTRACT

Step precision winding is a widely used bobbin winding method in industry, especially for dyeing bobbins. It is important to adjust winding parameters in an optimum way to obtain optimum hardness variation and best dyeing performance. Main winding parameters are winding pressure, crossing angle and yarn tension. This paper presents a research investigating the effect of main winding parameters on hardness distribution in radial and longitudinal directions of bobbins wound with step precision winding. Bobbins are produced from Ne 30/1 and Ne 10/1 cotton yarns. Bobbin hardness is measured by a new instrument called UNITORQ, which enables the measurement of relative bobbin hardness in radial and longitudinal directions with small increments of distance. It is found that crossing angle affects mainly longitudinal hardness variation while radial hardness variation is determined and affected in a large variation interval by winding tension. Winding pressure is seen to have no significant effect on winding hardness distribution in both radial and longitudinal directions but it determines bobbin hardness level together with winding tension and crossing angle.

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KEYWORDS

Winding density, winding hardness, hardness distribution, step precision winding, winding parameters

1. INTRODUCTİON

Bobbin winding is an important process in textile industry and an improper winding can cause irreversible results such as material loss or reduced product quality and lower process efficiency. Bobbins are wound with appropriate winding parameters to obtain the required hardness depending on the requirements of dyeing, warp preparation, weaving and knitting processes. Bobbins to be dyed are wound with a lower density so that dyeing liquid penetrates into the all regions of bobbin homogeneously. Those bobbins intended to be used as a weft or warp yarn are wound with relatively higher density to eliminate yarn slough off during unwinding. It is expected that yarns are unwound from the bobbins during warping and weft insertion in weaving with minimum tension variation for high efficiency. Yarns are also subjected to different stresses inside the bobbins. This can cause some elasticity and tenacity loss. For evenness of dyeing, minimizing elasticity and tenacity loss and minimum tension variation during unwinding, bobbin density distribution should be optimized. There are some published materials in the literature on bobbin hardness or density variations.

Özdemir and Oğulata studied the effect of winding density and yarn count on dyeing levelness of cotton yarns [1]. For this purpose, bobbins were wound with three different yarn counts (Ne 30/1, Ne 40/1, Ne 50/1) and three different package densities. They concluded that bobbins wound with thin yarns showed less color difference compared to the ones wound with thick yarns [1]. Mattison investigated the effect of winding density profiles on dye levelness in package winding [2]. He produced bobbins on a precision winding machine using polyester and cotton yarns with different tension profiles. In this way, he obtained twenty-seven different density profiles. After the measurements, he concluded that density profiles were not identical to yarn tension profiles and density of innermost layers had significant effect on dyeing levelness. It was also concluded that the parameters other than winding density profile (dye leak, position of the bobbing in dyeing spindle, etc.) influenced dyeing levelness more [2]. Yang and Mattison

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investigated the effect of winding density and its distribution on dyeing levelness of cotton yarns wound with precision winding method [3]. They used Ne 20/1 cotton yarns (unwaxed) and changed winding tension from 10 to 30 grams in three steps. They concluded that packages wound with varying density profiles were dyed with better levelness than the packages having even density [3]. Shaid, Siddiquee and Rahman investigated the effect of reverse tension mechanism on cheese dyeing [4]. They applied a winding tension curve having an increasing profile with respect to bobbin diameter and wound Ne 32/2 and Ne 20/2 carded and combed yarns. After dyeing and conducting dyeing levelness measurements, they concluded that better dyeing levelness was obtained with increasing tension profile and the dyeing levelness was better with finer yarns. They also concluded that package to package and within package density variations were higher with carded yarns compared to combed yarns [4]. Hes explained the measurement principle of the bobbin hardness instrument “UNITORQ” and how to improve dyeing levelness using the hardness measurement results [5]. He also investigated how to reduce yarn elasticity loss as well as breaking strength and breaking load decrease based on the hardness measurement results obtained with “UNITORQ” instruments [5]. Chemani and Halfaoui investigated the winding density distribution of cylindrical and conical wound bobbins theoretically [6]. They presented the relation of the change of the specific density of the winding yarn over the entire length of a spool having spherical ends. They concluded that in the ends of the spool is wound amount from yarn of 1.5 to 2 times the average amount which is in the middle because of the sudden change of the winding speed due to change in the direction of movement of the yarn and this caused the specific density change over the length of the bobbin. They also presented empirical equations based on the experimental results for winding densities between the middle and ends of bobbin [6]. Eren et al. investigated the effect of main winding parameters on bobbin hardness distribution in radial and longitudinal directions using 150/48 denier textured semi dull polyester yarn [7]. They showed that crossing angle and winding tension had the significant effect on bobbin hardness distribution and winding pressure, winding tension and crossing angle all affected and determined hardness level in a bobbin.

Winding parameters are of critical influence on bobbin hardness level and its distribution and therefore bobbin dyeing levelness and yarn unwinding behaviour. The research available in the literature does not explain bobbin hardness distribution precisely in radial and longitudinal directions due to probably the absence of instrument measuring bobbin hardness in a small area. This paper presents a research investigating the effect of winding parameters of yarn winding tension, crossing angle and winding pressure on longitudinal and radial winding hardness variation in step precision winding. Use of a new bobbin relative hardness measurement instrument, developed by Lubos HES, enables the measurement of bobbin hardness in longitudinal and radial directions with very small increments due to its small cross section of measuring needle [5].

2. Experimental work

There are three main parameters affecting winding hardness and hardness variation in bobbin winding process. These are crossing angle, winding tension and winding pressure. An experimental work was designed and carried out. Ne 30/1 and Ne 10/1 cotton yarns were wound with step precision winding on SSM PW2-W fastflex^{TM} DIGICONE$^{®}$ winding machine with step precision winding. As tension change with respect to bobbin diameter during winding is expected to affect on winding density level and variation, a variable tension with different profiles was applied during winding. Yarn numbers, tension profiles, crossing angles and winding pressures used in the experimental work are presented in Table 1.

As seen from Table 1, four tension profiles, three crossing angles and three winding pressures were employed in the experimental work for each yarn number. Eight bobbins were produced with the combination of these three parameters for each yarn number. Also on winding machine, bobbin edge softening was applied with variable stroke of traverse motion. Variable stroke of traverse motion was kept constant during all the experiments.

Table 1. Winding parameters for the experimental work.

No	Yarn number	Winding Tension (cN)	Crossing Angle (°)	Winding Pressure (N)
1	Ne 30/1	20 cN (constant)	20	10
2	Ne 30/1	20 cN (constant)	30	10
3	Ne 30/1	20 cN (constant)	40	10
4	Ne 30/1	20 cN (constant)	30	5
5	Ne 30/1	20 cN (constant)	30	15
6	Ne 30/1	10 cN-20 cN (linear increase)	30	10
7	Ne 30/1	10 cN-20 cN (linear decrease)	30	10
8	Ne 30/1	10 cN (constant)	30	10
9	Ne 10/1	40 cN (constant)	20	10
10	Ne 10/1	40 cN (constant)	30	10
11	Ne 10/1	40 cN (constant)	40	10
12	Ne 10/1	40 cN (constant)	30	5
13	Ne 10/1	40 cN (constant)	30	15
14	Ne 10/1	20 cN-40 cN (linear increase)	30	10
15	Ne 10/1	40 cN-20 cN (linear decrease)	30	10
16	Ne 10/1	20 cN (constant)	30	10

Bobbin hardness was measured using UNITORQ instrument with 10 mm increments in both radial and longitudinal directions [5]. Four measurements were taken with 90 degrees of intervals around the bobbin for each position and average value was calculated as the relative bobbin hardness at this position. As shown in Figure 1, the needle of the device is inserted into the bobbin at around 40 mm depth and then the needle is rotated in anticlockwise direction by hand until the highest data is recorded. The instrument detects the reaction torque by a torque sensor against the rotation of the needle. This corresponds to the relative hardness of the bobbin at this position. UNITORQ instrument measures the bobbin relative hardness between 0 and 120 $*10^{-3}$ Nm. This instrument has the advantage of conducting the measurement up to 40 mm depth. Because of a small cross-section area (1.60x0.9 mm^2 with sharp tip) of its needle, relative hardness can be measured easily from all positions and angles with this instrument. Figure 2 shows measurement positions on the bobbin. Measurement points shown as (x) in radial direction with 10 mm increments from inside to outer side of the bobbin in Figure 2a. (1), (2), (3) and (4) indicate four measurement line on top of the bobbin with an angle of 90 degrees. Measurement points shown as (x) in longitudinal direction with 10 mm increments from the left (1) to right hand side (1') of the bobbin in Figure 2b. Crossing angle (α) is defined as the angle between two crossing yarns on the bobbin. Measurements were carried out by the same person with the same speed of needle rotation and same angle of needle penetration into the bobbin to minimize measurement errors.

Figure 1. UNITORQ bobbin hardness measurement device and measurement method [5].

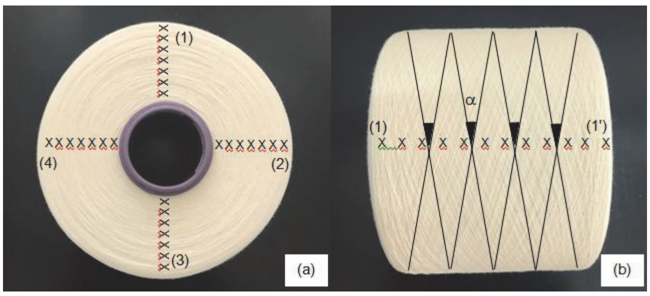


Figure 2. Measurement positions on the bobbin: a) Measurement points shown in radial direction. b) Measurement points shown in longitudinal direction.

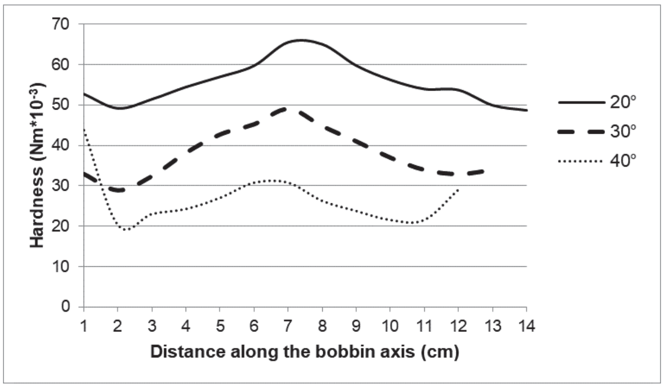
3. RESULTS AND DISCUSSION

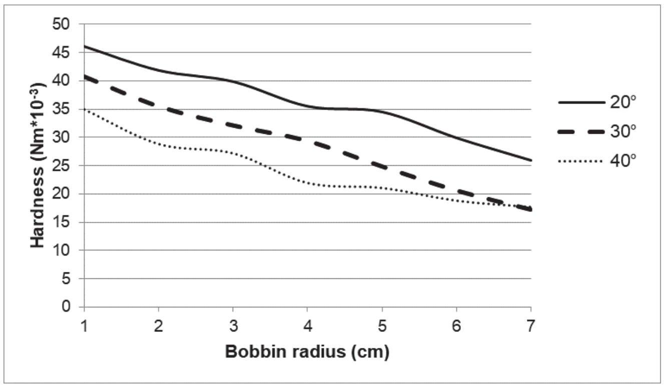
Effect of Crossing Angle on Bobbin Hardness Distribution

As shown in Figure 2b, crossing angle is defined as the angle between two crossing yarns on the bobbin and it is one of the critical parameters affecting bobbin winding quality. Bobbins were produced with 20, 30 and 40 degrees of crossing angles to investigate the effect of crossing angle on hardness distribution both for Ne 30/1 and Ne 10/1 cotton yarn. Winding pressure remained 10 N and yarn tension was adjusted to 20 cN and 40 cN for Ne 30/1 and Ne 10/1 yarn respectively and kept constant during winding. Measured hardness results are presented in Figures 3 and 4. As seen from all the figures, the bobbin hardness level increased with decreasing crossing angle because of increasing number of winds per bobbin length. Hardness level with crossing angle of 20 degrees corresponded to around twice of that of 40 degrees of crossing angle.

Figures 3a and 4a show longitudinal hardness variation for Ne 30/1 and Ne 10/1 yarn respectively. For both yarns, highest hardness was obtained around the middle region of the bobbins and it decreased towards the edges. The same variation in longitudinal hardness variation was observed with all three crossing angles. Hardness variation decreased with 40 degrees of crossing angle but it increased at the bobbin edges. Increase in hardness at bobbin edges is thought to be due to a longer stopping and speeding up periods of the yarn guide because of its higher speed with higher crossing angles. Less hardness variation between the middle and bobbin sides is attributed to much lower hardness level with 40 degrees of crossing angle. Hardness of bobbins in longitudinal direction showed an interesting variation. Normally, the hardness in longitudinal direction is expected to be constant due to a constant traverse speed and yarn lay out in cylindrical bobbins. Higher hardness around the middle and lower hardness towards the sides of bobbin are general hardness variation pattern measured in bobbins with all the parameters. Subjective assessments by hand check and measurements by shore hardness measurement device also approved this hardness variation. In addition to this, yarn traverse motion was analyzed by a stroboscope and no deviation was observed from linear motion that would cause such longitudinal hardness variation. It is thought that the longitudinal hardness variation is caused by yarn tension change during yarn traverse through bobbin length.

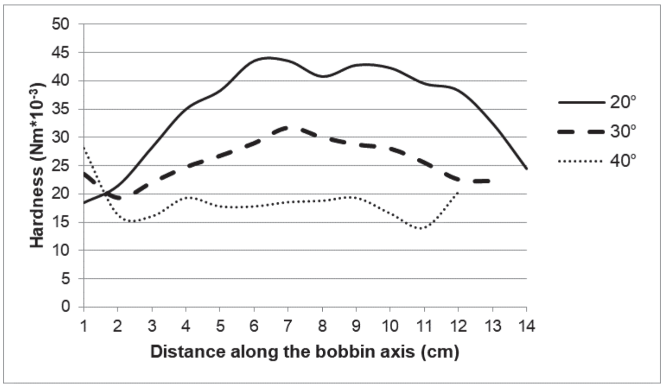
As for hardness variation in radial direction (Figure 3b and Figure 4b), it decreased with respect to bobbin diameter at almost the same ratio in all crossing angles. It can be said that crossing angle did not have any significant effect on hardness variation in radial direction. Decrease in bobbin hardness with increasing diameter at constant tension can be explained by the increasing pressure of outer yarn layers towards inside the bobbin. As a result of this, the density or hardness increases at lower layers as bobbin diameter increases.

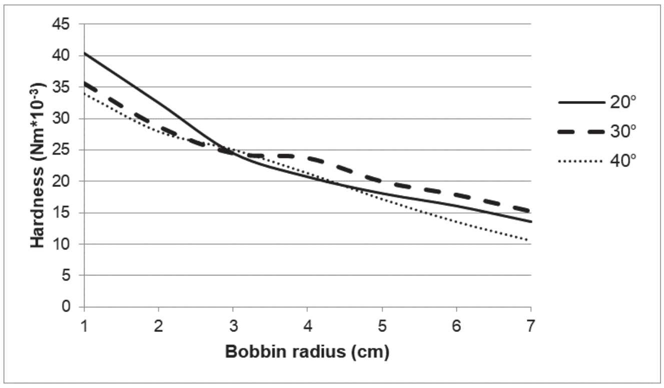




a. **b.**

Figure 3.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= Ne 30/1, winding tension=20 cN, winding pressure=10 N).





a. **b.**

Figure 4.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= Ne 10/1, winding tension=40 cN, winding pressure=10 N).

A very similar hardness distribution in longitudinal direction is obtained with 150 denier polyester yarn winding with the same crossing angles, winding tensions and winding pressure [7]. This result shows that the above mentioned longitudinal hardness variation is a general characteristic of winding process and is not dependent on yarn material.

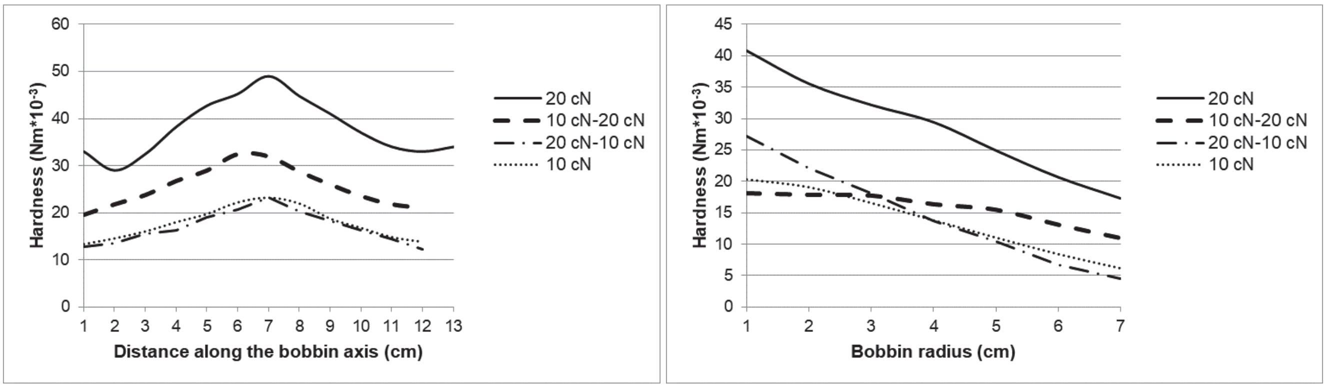
Effect of Winding Tension on Bobbin Hardness Distribution

Effect of winding tension on longitudinal and radial hardness variation was investigated by carrying out bobbin winding with decreasing, constant and increasing tension change with respect to bobbin diameter. Winding pressure was taken as 10 N and 30° crossing angle was employed in winding of both Ne 30/1 and Ne 10/1 cotton yarn. Results are shown in Figure 5a and 6a for longitudinal hardness variation and in Figure 5b and 6b for radial hardness variation. Figure 5a and 5b show the results of Ne 30/1 and Figure 6a and 6b present the results of Ne 10/1 cotton yarn.

As seen from Figure 5a, longitudinal hardness curves changed as was explained above for crossing angle. Higher hardness was obtained in the middle of the bobbin and it decreased towards the bobbin edges with all tension profiles. Longitudinal hardness level increased with increasing tension. Highest hardness level was recorded with 20 cN constant tension and the lowest with 10 cN constant tension. Hardness level with increasing tension change (from 10 to 20 cN) remained between hardness levels of 10 cN and 20 cN winding tensions. In the case of decreasing yarn tension change (from 20 cN to 10 cN), hardness level approached bobbin hardness for 10 cN tension. Similar hardness change was observed in Ne 10/1 yarn bobbin (Figure 6a). Bobbin hardness with increasing tension change (20 cN to 40 cN) approached hardness curve of 40 cN (constant) and hardness variation with decreasing tension change (40 cN to 20 cN) approached 20 cN (constant) bobbin hardness curve.

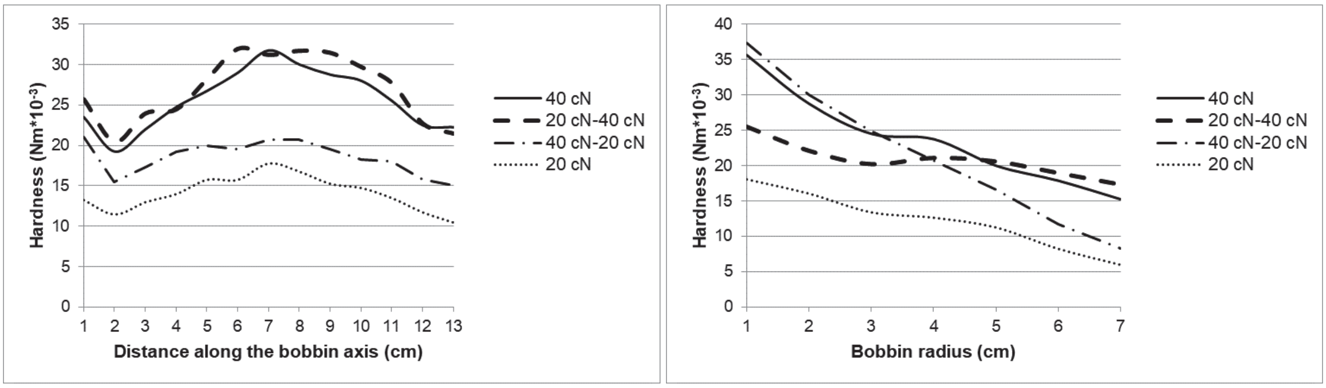
Effect of winding tension on hardness variation in radial direction is seen in Figure 5b and 6b for Ne 30/1 and Ne 10/1 cotton yarn respectively. Hardness change showed almost the same pattern in both Ne 30/1 and Ne 10/1 yarn. With constant winding tension, the hardness decreased almost linearly with increasing bobbin diameter. At higher constant tension, reduction in bobbin hardness with bobbin diameter became higher both in Ne 30/1 and Ne 10/1 yarn. Decreasing winding tension from 40 to 20 cN and from 20 to 10 cN for Ne 10/1 and Ne 30/1 yarn respectively increased yarn hardness reduction between empty to full bobbin diameters. Hardness change decreased at only a limited amount with yarn tension increase from 20 to 40 cN and from 10 to 20 cN for Ne 10/1 and Ne 30/1 yarn respectively. This result shows that hardness change in radial direction can be shaped at a large interval by determining yarn tension change with respect to bobbin diameter. By adjusting the amount of tension increase, bobbin hardness change in radial direction can have even increasing values.

Similar longitudinal and radial hardness variation was observed in 150 denier polyester yarn as seen in Figure 7a and 7b with 4 different winding tension variation. Winding of 150 denier polyester yarn was carried out with the same 4 different winding tension variations, winding angle and winding pressure of Ne 30/1 cotton yarn. As in cotton yarns, highest hardness value was measured around the middle of bobbin length and it decreased towards the bobbin sides (Figure 7a). Some hardness increase occurred at the bobbin edges due to lower average speed during slowing down and speeding up of yarn guide. Hardness of bobbin in the case of increasing tension change during winding approached the hardness of constant higher tension and bobbin hardness with decreasing tension change was obtained closer to the hardness curve of constant lower yarn tension (10 cN).



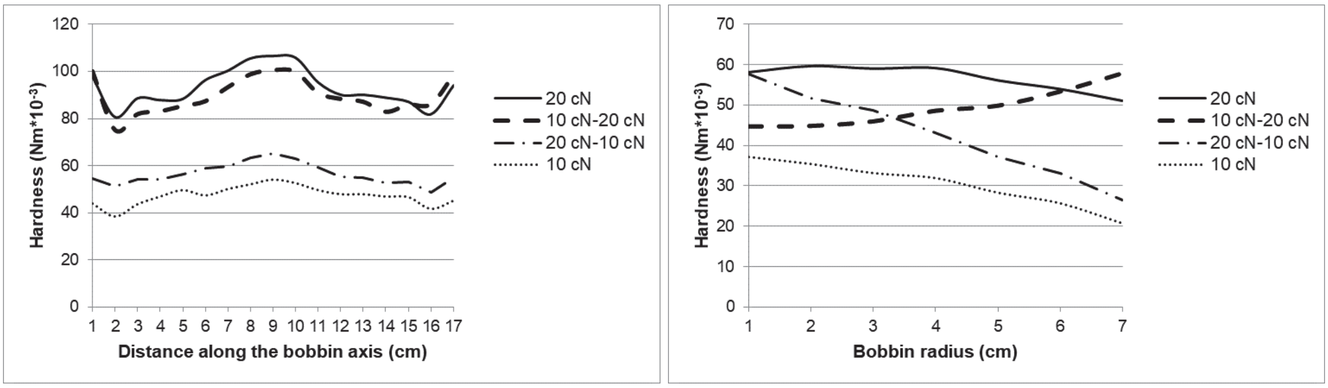
a. b.

Figure 5.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= Ne 30/1, crossing angle=30°, winding pressure=10 N).



a. b.

Figure 6.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= Ne 10/1, crossing angle=30°, winding pressure=10 N).



a. b.

Figure 7.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= 150 denier polyester, crossing angle=30°, winding pressure=10 N).

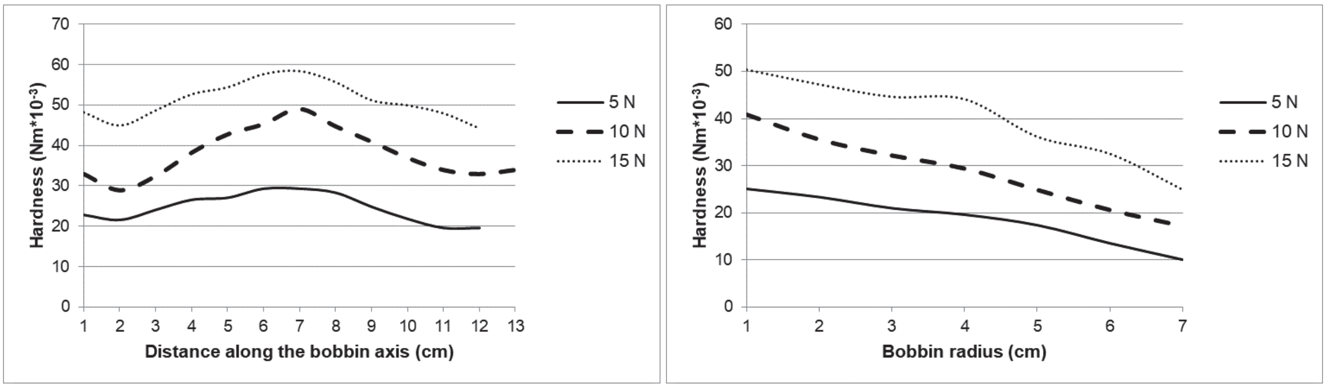
Figure 7b shows hardness change with respect to bobbin diameter for different winding tension changes. As seen from the curves, bobbin hardness decreased with increasing bobbin diameter at both constant 20 cN and 10 cN winding tensions. Bobbin hardness decreased at a larger amount (almost half of its initial value) with winding tension decreasing from 20 cN to 10 cN. In the case of increasing winding tension, bobbin hardness showed an increasing trend with bobbin diameter. Relative bobbin hardness value increased from 45 to 60 when yarn tension increased from

10 cN to 20 cN. Hence, bobbin hardness in bobbin radial direction can be shaped at a large interval with decreasing and increasing winding tension profiles by adjusting the amount of winding tension change between empty and full bobbin diameters. Compared to cotton yarns, yarn tension change with polyester yarn winding had a more sensitive effect on hardness change in radial direction. This is important especially with bobbins to be dyed.

Effect of winding tension on radial hardness variation was found different for increasing and decreasing winding tension profiles in a previous study [7]. This might be due to wrongly adjusted winding tension in the bobbin machine used in the previous study.

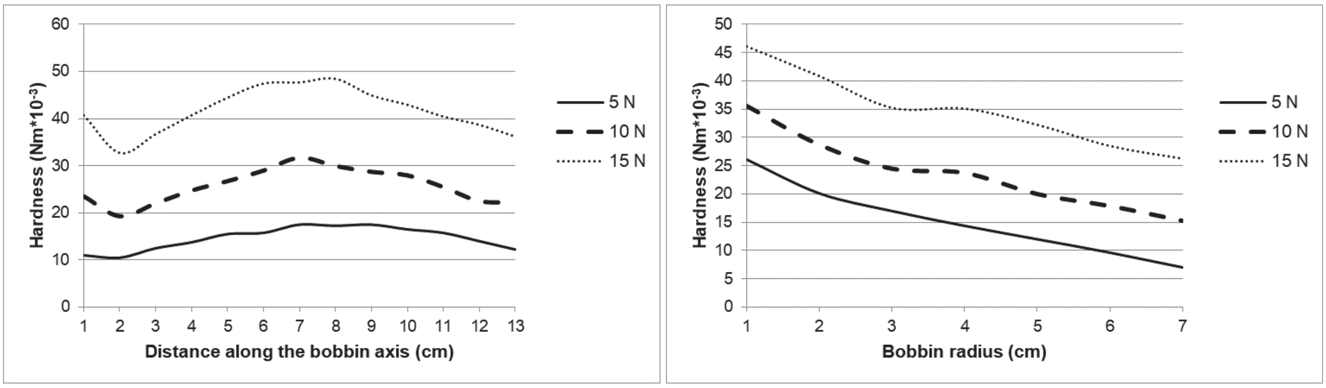
Effect of winding pressure on bobbin hardness variation

Effect of winding pressure on bobbin hardness variation was investigated by producing bobbins with 5 N, 10 N and 15 N winding pressures. On the experimental winding machine, the pressure between bobbin and the cylinder is adjusted by the spring force. Crossing angle was taken as 30 degrees. Figure 8a and 8b show bobbin hardness variations in longitudinal and radial directions respectively for Ne 30/1 cotton yarn and Figure 9a and 9b show the results for Ne 10/1 cotton yarn. Winding tension was kept constant at 20 cN and 40 cN for Ne 30/1 and Ne 10/1 cotton yarn respectively. As expected, bobbin hardness level increased with increasing winding pressure. This can be seen from approximately linear bobbin hardness variation in radial direction. Approximately linear curves shifted upwards with increasing winding pressure. In longitudinal direction, hardness variation decreased with decreasing winding pressure. Higher winding pressure caused hardness in the middle and also at bobbin edges to increase. The same hardness variation occurred in longitudinal direction for both Ne 30/1 and Ne 10/1 cotton yarns.



a. b.

Figure 8.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= Ne 30/1, winding tension=20 cN constant, crossing angle=30 degrees).



a. b.

Figure 9.a. Longitudinal hardness variation **b.** Radial hardness variation (yarn number= Ne 10/1, winding tension=40 cN constant, crossing angle=30 degrees).

Results presented in Figure 8a and 8b and Figure 9a and 9b show that winding pressure does not have any significant effect on hardness variation in both radial and longitudinal directions. It only determines general hardness level.

4. CONCLUSION

Following conclusions can be drawn from this study.

- Bobbin hardness showed a variable form which took highest values around the middle and decreased towards bobbin sides. At edges, some increase in bobbin hardness was observed especially with lower hardness levels despite the application of edge softening. It is thought to be caused by yarn tension change during traverse motion and its effect on yarn positioning on the bobbin.
- Winding pressure showed no significant effect on bobbin hardness variation in both longitudinal and radial directions. It had significant effect on hardness level.

Higher the winding pressure the higher the bobbin hardness level, vice versa.

- Crossing angle is found to be a critical parameter affecting especially hardness level in winding. Lower crossing angle increased hardness level as it increased number of wind per bobbin length. Crossing angle also affected hardness change in longitudinal direction. Hardness difference between the middle and sides of a bobbin decreased at crossing angle of 40 degrees compared to 20 degrees.
- Constant, increasing and decreasing tension profiles showed a very significant effect on radial hardness variation as well as general hardness level. Hardness in radial direction decreased with increasing bobbin diameter at constant winding tension at a similar ratio. Bobbin hardness in radial direction decreased at a higher rate when yarn tension changed from 20 to 10 cN with Ne 30/1 cotton yarn and 40 to 20 cN with Ne 10/1 cotton yarn. Reversing tension change from 10 to 20 cN and 20 to 40 cN caused a very limited decrease in hardness in radial direction for cotton yarns. Changing yarn tension from 10 to 20 cN caused even an increase in hardness in radial direction with increasing bobbin diameter for 150 denier polyester yarn. Hardness variation in radial direction of bobbin can be affected at a large interval by adjusting winding tension change with respect to bobbin diameter which is important especially for dyeing bobbins.
- Advantage of using the UNITORQ device is that it enables to determine bobbin hardness variations in both radial and longitudinal directions with small increments and has potential to analyze especially dyeing levelness problems in a more accurate way.
- Measuring bobbin hardness by hand might look a disadvantage of the device. But, the repeated measurements by the same person paying attention to the needle penetration angle and turning speed produced very close hardness values. Therefore the hardness results presented in this paper can give a general picture of hardness distribution of a bobbin.

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