Influence of Fiber's Surface Morphology Change on Anti-pilling Performance of Woolen Knitted Fabric

Masukuni Mori[1], Takako Fujiumoto[2] and Machiko Murakami[3]

[1]*Mori Consultant Engineering Office Japan,masukuni@msc.biglobe.ne.jp*

[2]*Hokkaido University of Education,.Japan, fujimoto.takako@s.hokkyodai.ac.jp*

[3]*Gifu City Women's Junior College,Japan*

Abstract: Although the main factor controlling pill generation at the time of wearing wool knitted articles is the knitting structure of the raw material; the strength of yarn, the number of twist of yarn, the fabric design, the gauge number and so on, it is influenced ~~also~~ by the dyeing / finishing method of the knitted fabric after knitting as well.

In this paper, the influence of change in surface morphology of raw material fiber on pill generation is investigated (along with mechanical and physical properties of fabrics). Fabric samples are treated with several physicochemical processing. The difference in condition of scales and the relation with pill generation were discussed and clarified. The plain knit wear is widely used for sportswear and child's underwear subjected to high activity. Such clothing necessitates comfortable and soft touch and besides the surface of the clothing must be kept smooth and anti-pilling condition. These requirements are hopeful for comfortable clothing life. Thus, the present paper is believed to be a suitable topic relevant to Kansei Engineering.

Keywords: Pilling, Surface morphology, Wool-Knit, Physicochemical treat.

1. INTRODUCTION

The generation of the pill at the time of wearing wool knitted fabrics mainly originates from properties of the raw material, the number of twist of the yarn, the fabric design and the gauge number, and others. But sometimes such a design is unwillingly employed because of aesthetic necessity and soft handle. For child clothes and sportswear subjected to high activity, anti-pilling fabric are required. The pilling phenomenon is largely developed when the yarn as the raw material is long and tough, and the structure of knit composed of yarns with low twist density is coarse. The generation of the pill on the wool knitted fabrics is also influenced by the post processing of dyeing and finishing. In our preceding work [(Mori et al 2013), we discussed about the influence of dyeing and finishing processes on the performance of woolen and worsted fabrics. And it was confirmed that handling and feeling of the fabrics could be modified by physicochemical finishing processes. In the present work, first the generation of the pill was investigated for wool knitted fabrics subjected to 4 kinds of post physicochemical processing such as Chlorination (Breck et al ,1989), NARS shrink-proof (Cadamone et al,2004), Argon low temperature plasma(Mori et al.2006) , and Polyuretane resin treatment and so on in which anti-pilling function is expected to be endowed. Next, the relation of the unevenness on the fiber surface, i.e. the state of scale height to the pilling nature was investigated in that the generation of pilling was ascribed to entanglement of fluffs on fabric surface. The state of the pilling was comparatively evaluated from 3 kinds of information that the number of pills on a prescribed area of the test fabric after pilling test, the number of pills dropped out and the size of the pill. The 3 kinds of information here are (ⅰ) Five-rank evaluation based on JIS-1076-1992, (ⅱ) Average number of pills generating on a area of 12×10 cm2 of the test fabric, and (ⅲ) number of pills dropped out into the box of tester. AS a result, high correlativity of the scale height with number of Pills (R2=0,71)was found out. This means that the generation of pilling is easily brought about by large difference between low and high scales. To further confirm this correlation, the scale height must be measured, and the measurement by AFM(Atomic Force Microscope)is now under consideration.

2. EXPERIMENT

2.1. Materials

The sample used is composed of merino wool yarns of 20.1～21.0 μm in diameter 2/60 (33.3 dtex) . The structure is plain weave. As to the count of twist, lower twist is set 685Z, while upper twist is set 685S. Coarse density is 153/10cm and wale density is 134/10cm, respectively, and weigh is 178g/cm^2. The physical properties of materials are summarized in Table 1.

Table 1: Physical properties of materials

Materials	Yarn		Knitted Fabric		
	Count	Twist	Density(/10cm)		Weight(g/cm^2)
			Coarse	Wales	
100%Merino wool(20.1-21.0μm)	**33.3dtex**	**685Z/685S**	153	134	178

2.2. Details of finishing processes

Samples are classified into 5 fabrics. 4 kinds of physicochemical treatments were subjected to grey fabric.

- Sample 1: Grey fabric; Knit wool fabric described in 2.1
- Sample 2 in which chlorination treatment was practiced on sample 1 and scales on the surface of wool were removed.
- Sample 3 in which surface modification by NARS processing was subjected to sample 1.
- Sample 4 in which aqueous emulsion type resin processing was practiced on sample 1.
- Sample 5 in which Argon Low Temperature Plasma exposure was subjected to sample 1.

2.2.1. Chlorination treatment

Fabric samples placed in a dyeing bath were dipped in water at 20 to 25 ℃ under a liquor to wool ratio of 20 : 1, and the amount corresponding to 0.05% non-ionic surfactant was added as a penetrating agent to the dyeing bath. The dyeing bath was stirred until the fabric samples were perfectly soaked in it. Then, solutions of 3.0% (o.w.f. as active chlorine) DCCA and 5.0% (o.w.f.) sodium pyrophosphate ($Na_2P_2O_7 \cdot 10H_2O$) were added, further acetic acid was added to adjust pH within the range of 5.5 to 6.0, and the resultant solution was maintained for a period of 20 min at this temperature. The temperature of the solution was then raised to 35 ℃ in 10 min, and maintained for 20 min. 6% (o.w.f.) sodium hydrogen sulfite ($NaHSO_3$) was further added, and after the temperature of solution had been raised to 60 ℃, the solution was maintained at this temperature for 10 min. The treated fabrics were rinsed and dried by air. The fabric samples treated with such chlorination processing were subjected to property measurements.

2.2.2. NARS shrink-proof processing

According to a modified method of the procedure described in U.S. Agricultural Research Service (Wyndmoor, PA 19038), treatments to wool fabric were carried out at conditions of pH 10.2, 30 ℃, period of 30 min and liquor to wool ratio of 20 :1 using a laboratory dyeing machine containing 1 g/L Ttriton X-114, 3 g/L NaOH, 1 g/L gluconic acid, 3 g/L dicyandiamide, and 12 g/L H_2O_2 (35%). After such treatment, the fabrics were rinsed until reaching neutral pH. Successively the treatment by enzyme was carried out at 50 ℃ and pH 6.0 for 40 min in a bath dissolving 1.5g/L triethanolamine (TEA), 1g/L Triton X-114, 1.5% (o.w.f.) Na_2SO_3 and Esperase 8.0LTM (Novoenzymes, North America, Flaklington, NC). After the treatment, the enzyme was deactivated at the conditions of 80 ℃ and period of 10 min. The fabrics were rinsed and dried by air.

2.2.3. Water soluble polyurethane resin treatment

As for sample, aqueous emulsion type resin Supeperflex R 5002 is in a state of 5 % solution. Pad was extracted, and it was cured during 1 min at 130 ℃ after the drying process.

2.2.4. Argon low temperature plasma treatment

Plasma reactor used is a type DSSO-422 (Daia Sinku Co., Ltd.). The discharge frequency was fixed at 13.56 MHz. Plasma treatment was carried out by the following procedures. The sample was placed in the reactor, and the reactor was evacuated to 0.001 Torr (0.13 Pa). Then argon (Ar) was fed into it at a volumetric flow rate of 10 mL/min. The electric power for plasma discharge was fixed at 100 W. The internal pressure of the reactor was maintained at 0.1 Torr (13.3 Pa) during a plasma-treatment time of 300 s. The treated fabric samples were finally rinsed with water and dried by air, and then they were subjected to property measurements.

2.3. Pilling test method

Pilling conditions for treated and untreated sample fabrics are based on the JIS L-1076-1992 (ISO 12945-1) method. The measurements for the treated fabrics were compared with the measurement for the untreated fabric. According to the method, the ranking from the first to the fifth rank is determined. To determine more accurate ranking of the fabric, in this study, the information on both the number of pills in the 12×10cm area and the number of the pills dropped out was employed.

2.4. Breaking strength

Items of breaking strength, elongation for an untreated fabric and 4 kinds of treated knit fabrics were measured based on JIS L-1095 by means of tension tester AG-IS 10KN (Shimadzu Manufacturing Co. Ltd., Japan). The average breaking strength (N) and elasticity (%) were determined under the conditions of number of samples = 50, sample length and width = 200 mm and 50 mm, respectively, initial load = 0.05N, and pulling speed = 200 mm/min.

2.5. Bursting strength

The bursting test was executed by means of constant elongation method based on JIS-L1096-8.16. First, five test pieces of 8 cm diameter are cut out and then the test piece with the backside upward is smoothly fastened to the clamp of internal diameter 4.4 cm without wrinkling and loosing. The force N when the test piece is broken down by a pushing rod at a pressing speed of 10 cm/min is measured. The pushing rod has the diameter of 2.5 cm and the tip of the pushing rod has the radius of curvature of 1.25 cm. The value of force N is averaged by 5 measurements, and is expressed by tenth's place.

2.6. Observation of fiber surface morphology

A 3D profile microscope (Keyence VK 8500) was used on the direct magnification of 1000 at a plane special resolution of 0.13 μm and at the repetition accuracy of 0.02 μm. The unevenness on the surface of each sample; unevenness in μm on 7 to 8 sheets of scale was observed by means of this microscope, the unevenness of scale was compared with each other for samples with and without treatment.

2.7. Dyeing method

The dyeing property was discussed to compare chemical changes of worsted wool caused by a variety of physicochemical treatments in terms of color intensity, and the relation to fabric handling was confirmed. In the present work, also treated and untreated wool fabric samples were dyed using a dyeing machine Colorpet 12LMP-E (Nissen Co.). The samples were immersed in a 0.1% solution of surfactant acting as penetrating agent under the liquor to wool ratio of 20:1 for 10 min. The dyestuff was added to the surfactant solution at a temperature of 50 ℃, then the temperature was raised to 100 ℃ at a rate of 1.5 ℃/min and maintained at this temperature for 20 min under a gentle stirring. The dyeing process was further continued for 40 min at 100 ℃ in the presence of 2.0% (o.r.f.) acetic acid (99%) for adjusting pH at 4.0 to 4.5. The dyed samples were thoroughly washed and dried. The dyestuff used was 5.0% (o.r.f.) Lanasol Black CE-R.

2.8. Dyeing intensity

Color of sample was measured by means of spectro-colorimeter Minolta CM-3600D. Power source was D65, visual angle was set 10°, and the sample size was 5 cm×5 cm. Dyeing yield was measured from reflection ratio at the maximum wavelength of absorption, and K/S was calculated using Kubelka-Munk equation. L*, a* and b* on CIELAB system were obtained for the dyed samples and L* was used for the reference value of dyeing yield. Reflectance of the treated wool was measured, and L* was calculated according to Kubelka-Munk equation.

2.9. Objective evaluation of fabric handling by KES

Mechanical properties and fabric handling were evaluated by objective evaluation method using KES (Kawabata Evaluation System) procedure(Textile Machinery Society Japan,1998,Kawabata,1980) for untreated and treated wool fabrics. Tensile, bending and shearing were measured for course and wales directions, and both compression and surface properties were measured together with thickness and weight of fabric. Total Hand Value(THV) was calculated using KES and measurements of mechanical properties outlined above. According to five-rank evaluation,THV=1 means poor and THV=5 means excellent The size of fabric was exactly 20 cm×20 cm, and kept at 20℃ and 65% RH. For a period longer than 24h.

3. RESULTS AND DISCUSSION

3.1. Test results on pilling

3.1.1. Ranking of pilling and its evaluation data

The rank of pilling based on the JIS L-1076-1992 (ISO 12945-1) method, and the numbers of the pills and the pills dropped out are listed for grey fabric and the fabrics treated by 4 kinds of finish processing in Table 2. In the same table, the total (comprehensive) ranking judged from both the rank based on the above JIS method and the information on the numbers of pills and the number of pills dropped out is also shown. It is apparent in Table 2 that NARS processing brings about the least generation of the pill, and according to JIS L-1076-1992 the 5th rank is attained and in chlorination processing the 4th rank is realized. For untreated (grey) fabric the rank is 4. By finish processing, the ranking can be improved by 1 to 2 ranks.

Table 2: Rank of pilling and state of pilling generation

Process Name		JIS L-1076-1992	Pills /12×10cm^2 1)	Dropped Pills2)	Comprehensive ranking3)
0	Untreated	3	94,74,70,84/4 =80.8	25	4
1	Chlorination	4	18,15,12,16 =15.3	8	2
2	NARS	5	1,0,2.3/4 = 1.5	0	1
3	Polyurethane	3-4	49,30,48,38 =41.3	11	3
4	LTP Plasma	3-4	50,54,28,44/4 =44	13	3

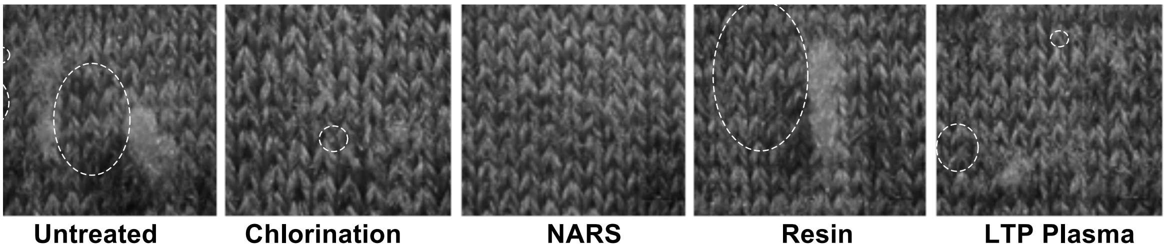
1) The average number of the pills generating in an area of 12×10 cm2 on two sets of cloths in warp and weft directions, i.e. 4 sheets, was employed in the evaluation by JIS L-1076-1992.

2) The number of the pills dropped out during test.

3) Comprehensive ranking judged from both the rank based on JIS method and the information on the numbers of pills.

3.1.2. Generation situation of the pill

Figure 1 shows the magnified photographs of untreated (grey) knit fabric and knit fabrics treated by 4 kinds of physicochemical processing. Some pills are seen on the surfaces of grey fabric, and the fabrics treated by resin and plasma, whereas no pill is seen on the surface of the fabric treated by NARS. Only some indication of generation of the pill appears on the surface of the fabric treated by chlorination processing.



＊ White dotted circle s represent shows the position and the size of Pill.

＊The number of Pills fixed within the limits is referred to Table 2.

Figure 1: Photographs (in 35% of magnification) of fabric surfaces and the numbers of the Pills dropped out on the based of the basis of JIS method.

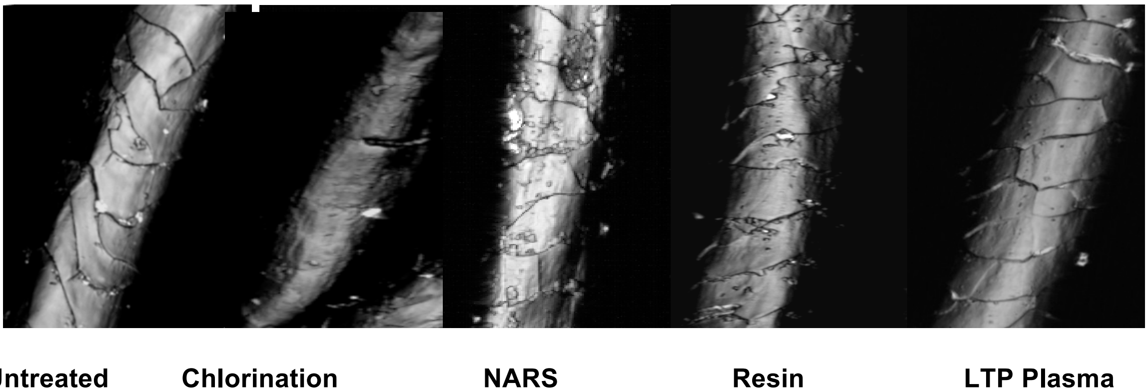


Figure 2: Photographs of the surfaces of the wool fibers without and with treated physicochemical processing.

Figure 2 reveals photographs of a single fiber taken by a 3D laser microscope equipped with extremely deep focus Keyence VK-8500. The single fiber was taken out of untreated (grey) fabric and the fabrics treated by 4 kinds of physicochemical processing. Scales on the surface of the fiber subjected to chlorination treatment are found to be completely removed, and only some trace of the scales is observed. There is almost no appreciable difference on the surfaces of the fabrics treated by resin and plasma, and the untreated fabric. On the other hand a little bit of scale remains on the surface of the fiber subjected to NARS treatment. But the scale is thinly worn away, and appears to make the scale and the fiber axis come closely into contact.

3.2. Unevenness of fabric surface, scale height and the number of the pill

Figure 3 shows the unevenness existing in between about 7 to 8 scales on the fiber surface or within about 100 μm in the longitudinal direction, namely, opening of the scale. The fibers subjected to observation were extracted from a grey fabric and the fabrics treated by 4 kinds of physicochemical processing. The unevenness was measured by means of a 3D laser microscope equipped with extremely deep focus, Keyence VK-8500. With chlorination treatment, scales are removed, and unevenness clearly lessens. NARS treatment lessens unevenness more, and the tip of the scale is found to be worn away.

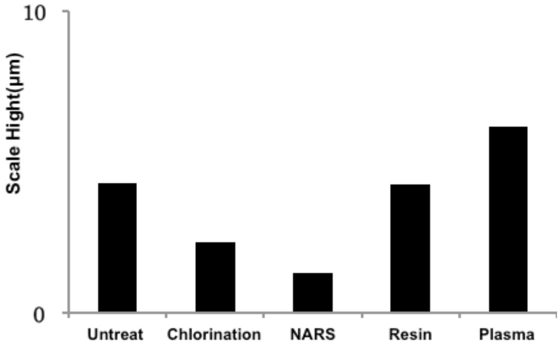


Figure 3: Scale height on the surface of the fiber subjected to each processing.

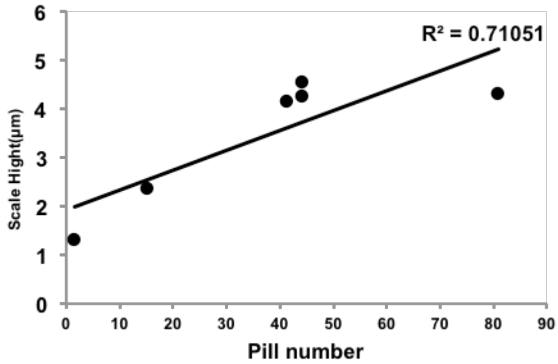


Figure 4: Correlation of scale height on the surface of fiber with the number of pills.

Next the relation of the number of pills on the surface of knit fabrics generating after pilling test executed, to the unevenness of scales on the fiber surface, namely, the state of opening of the scale was examined. Figure 4 indicates the relationship between these two factors obtained. The correlativity of the scale height with the number of pills is found to be high in that R2＝0.7105.

3.3. Tensile (Breaking) and bursting strength

Figure 5 shows tensile and bursting strength of the knit fabric. The knit fabrics used for evaluation of tensile and bursting strength were untreated knit fabric and 4 kinds of treated knits fabrics. This figure shows that the decrease in strength is the maximum in NARS-treated fabrics, and besides both kinds of strength in NARS-treated fabrics become lower than in untreated (grey) fabric.

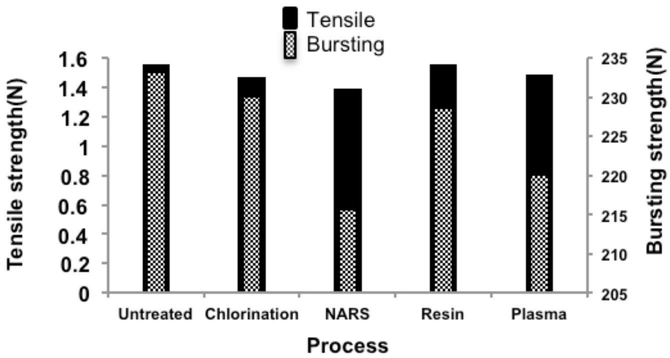


Figure 5: Tensile and bursting strength of the fabrics subjected to anti-pilling processing.

3.4. Handling

Total Hand Value(THV) was calculated from the basic physical properties on the basis of KES procedure for knitted fabrics treated with four sort of finishing processes. Calculated values of THV are shown in Figure 6. It is apparent that THV after NARS finishing amounts to 4.9 and the NARS finishing is superior in fabric handle.

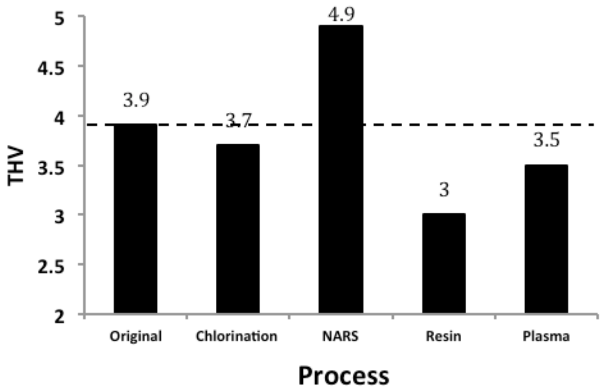


Figure 6: Comparison of THV each processed fabric.

4. CONCLUSION

It was confirmed that the anti-pilling nature for pure wool knit fabric could be improved by about 2 ranks by NARS finishing process. The feature of NARS treatment to wool knit fabric lies in low scale height, namely, close scale opening on the surface of the fabric, and the depression of the fabric strength. The depression of felt-shrinkage after hand-washing, and the dyeing nature, namely, dyeing intensity and iridescence of the treated fabric by NARS treatment can be markedly improved as compared to those of untreated fabric. Besides, the NARS finishing process is non-chlorine treatment and accordingly, the treated fabric still keeps a handling of the essential wool, as compared to the chlorination finishing process. Theoretically and clearly, there seems a close relationship between the generation of pills and the scale. If so, the chlorination treatment should be the best processing method from anti-pilling points of view. But actually NARS treatment was the best one instead of the chlorination in this work. Then, a special attention was paid to unevenness on the fiber surface after each processing. Now the unevenness on fiber surface is observed by means of Atomic Force Microscope (AFM), and is compared with each other. Besides, the selection of treatment agents and reinforcement agents to minimize the depression of the strength and to maximize the anti-filling nature is also the subject for a future study.

REFERENCES.

Breck A. et al (1989) Filzfestausrustung in langer Flotte ohne Vergilbung,*Melliand* Textilebericht **6.**452-454.

Cardamone M. et al.(2004) ,Wool Shrinkproofing by Chemical Enzymatic Methods, *Textile Res. J.*, **74**, 555-565

Kawabata S. (1980) “The Standardization and Analysis of Hand Evaluation” 2nd Ed. HESC ,Textile Machinery Society of Japan 28.

Mori M. et al (2006), Relation between Anti-Felting Properties and Physicochemical Properties of Wool Treated With Low-Temperature Plasma, Research Journal of Textile and Apparel” **10**(1)33-45

Mori M. et al (2013) Correlation with Itchy Feeling of “Fabric Handling” Change by Physicochemical Processing of Woolen Fabric, Fibers and Polymers **132**(14**)** 2202-2211

Textile Machinery Society of Japan (1998) pp. 15-29 “Manufacturing Performance and Mechanical Properties of Fabric” Amagasaki Insatsu, Osaka.

BIOGRAPHY

Short biography of author 1

1. Born in 1929
2. Retired from a dyeing and finishing company in 1996 after 45 year’s service
3. Established Mori Consultant Engineering Office just after retired
4. Got a Doctor Degree from Shizuoka University in 2006, Title of doctor thesis: Shrink-proofing of wool by low temperature plasma treatment
5. Now consultation service in and outside Japan

Hobby

Creation of original and novel fabrics for garments and picture appreciation

Short biography of author 2.

T. Fujimoto’s synopsis is:

Dr. Takako Fujimoto belonged to 1)Niigata University (1977-1981), and then has belonged to 2) Hokkaido University of Education (1992- at present) and has been professor since 1992. She has been i) Head, Japan Section of The Textile Institute of UK (2005-), ii) a member of council of TI, iii) a council member of Japan Research Association for Textile End-uses, iv) a visiting professor, University of University of New South Wales, Australia (1996.9-1997.3). Her major research areas in scientific achievement are a) theory of heat transfer of fibrous materials, b) mechanical properties and handle estimation of clothing fabrics, c) objective evaluation of clothing materials, d) durability of clothing materials. The number of her published original books is 5, of her published original papers and articles is around 130. She received three prizes and awards related to the above scientific achievements.