TEST OF MECHANICAL PROPERTIES OF KNITTED FABRICS MADE OF PAPER YARN

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ABSTRACT

Consumption of cotton and oil-based fibres types is a major problem because it needs the help of fertilizers and toxic pesticides to grow in many places. It is urgent to find less environmentally damaging alternative yarns for the manufacture of clothing and other textile products. This study investigates and gives information about textile fabrics of paper yarn made from Manila hemp. Knitted structures made of paper yarn; cotton and viscose are tested and compared. Also, a tensile strength test of the yarns is performed. The paper yarn has low shrinkage and no tendencies to pilling, great characteristics for fabrics to be used in the textile- and clothing industry. The handleability / knittability: a problem that has to be solved if the paper yarn is going to be used in the textile industry to a high extent in the future. Also, the high stiffness and hard grip of the paper yarn fabric must be solved.

Keywords: *paper yarn, knitting technology, tensile testing, washing fastness, pilling*

1. INTRODUCTION

Consumption of cotton and oil-based fibres types is currently a major problem because cotton is a rare commodity and is grown in many places in the world where it does not grow naturally with the help of fertilizers and toxic pesticides. This means that it is urgent to find less environmentally damaging alternative yarns for the manufacture of clothing and other textile products [1]. Another problem is that the demand for paper is decreasing because many people of today read newspapers and pay their bills on the Internet creating an overcapacity in the pulp industry. This industry is looking for new business opportunities for the future. One solution of these problems can be yarn made of paper and an alternative is the production of yarn from Manila hemp. Raw material for paper yarn comes from the plant Manilla hemp which then is processed almost the same way as for production of other types of paper. The paper is sliced into thin strips and twisted into a yarn that can be manufactured as a textile fabric. This type of paper yarn can perhaps be a future environmentally friendly alternative to cotton and oil-based synthetic fibres [2, 3]. With more research and developments in the pulp and paper industry maybe it can be possible to make the paper yarn of raw material from forests in Northern Europe, USA, and Japan in the future.

This study has been developed to investigate and to spread information about textile fabrics of paper yarn made from Manila hemp. It also focuses on knitted structures made of paper yarn and other fibres, cotton, viscose and polyester and test of properties the knitted fabrics [4, 5, 6]. Also a tensile strength test of the yarns is performed. The properties are then compared and analysed.

This study poses the following research questions:

Research Question One (RQ1): How is the handleability / knittability of fabrics made of paper yarn compared to conventional cotton viscose and polyester fabrics?

Research Question Two (RQ2): What are the mechanical properties, pilling and dimensional change - shrinkage of weft knitted fabrics made of paper yarn from Manila hemp, compared to conventional cotton viscose and polyester fabrics?

Research Question Three (RQ3): How is the tensile strength of paper yarn compared to cotton viscose and polyester yarns?

The research questions are answered through literature studies, company visits, and tests of yarn and knitted samples. All of the material samples were knitted at the University of Borås, The Swedish School of Textiles, where also all the test experiments were conducted.

2. EXPERIMENTAL

The yarns used in this study were paper yarns made from Manila hemp, cotton, viscose and polyester as showed in Table 1. The paper yarns are manufactured and sold by the Japanese company OJI Fiber Co., Ltd under the brand name OJO^{+} [7]. The aim was to compare the properties of commonly used materials in the textile and fashion industry with paper yarn [8].

Table 1. The yarns used in the tests.

Material	Yarn number	Yarn formation method	Manufacturer	Country
Cotton	Nm 61/1	Ring spinning	FIRST SPINNERS PLC	Nigeria
Viscose	Nm 60/1	Ring spinning	António de Almeida	Portugal
Polyester	Nm 68/1	Ring spinning	Caulliez Freres	France
Paper yarn	Nm 30/1	Twisting	OJI Fiber	Japan
Paper yarn	Nm 31/1	Twisting	OJI Fiber	Japan
Paper yarn	Nm 50/1	Twisting	OJI Fiber	Japan
Paper yarn	Nm 51/1	Twisting	OJI Fiber	Japan

Circular knitting Single Jersey machines were used to knit the samples. Initially a Monarch machine; gauge E28 was used in trials in the binding plain knitting. Also a Camber Velnit machine, gauge E18 was used in the beginning of the study. All the samples used in the pilling and dimensional, shrinkage tests were knitted on a Mayer & Cie Relanit 0.8 machine, gauge E12; specially build and equipped to knit stiff yarns [9].

Handleability (knittability): was studied in knitting experiments on the machines mentioned above. During these tests the knitting process and the outcome of it was studied and analysed in terms of the yarns knittability and inaccuracies of the knitted fabric.

Dimensional change – shrinkage: of the knitted fabrics were tested according to the ISO 3759:2011 standard at a temperature of 22 degrees in the room. The washing machine used was a Wascator, FLE12OFC, detergent was Skona white wash perfume free.

Pilling: was tested with a Martindale 2000 machine according to standard ISO 12945-2:2000. The tests were performed according to the face-to-face method where the sample body is rubbed against the fabric at various intervals 125, 500, 1000, 2000, 5000 and 7000 turns.

Tensile strength of the yarns:
were performed as stated in ISO 13934-1:2013 standard for the yarns used in the knitted samples in the other tests. Manufacturing of all knitted samples was performed under

following conditions: temperature: 23°C, air humidity: 45-49 % (RH) in the knitting laboratory at The Swedish School of Textiles, University of Borås according to Table 2.

Table 2. Paper yarn and reference yarn for knitting and testing.

Sample*	Yarn 1	Yarn 1 [Nm]	Yarn 2 [Nm]	Yarn 2 [Nm]
1	Paper	30/1	-	-
2	Paper	30/1	Polyester	68/1
3	Paper	30/1	Cotton	61/1
4	Paper	30/1	Viscose	60/1
5	Viscose	60/1	-	-
6	Cotton	61/1	-	-
7	Polyester	68/1	-	-
8	Paper	31/1	-	-
9	Paper	50/1	-	-
10	Paper	51/1	-	-

**Sample 1-8 are made in structure Piké Lacoste, sample 9-10 in plain knitting.*

This study is a part of a bachelor thesis in textile engineering at University of Borås, The Swedish School of Textiles 2015, title "Trikå av pappersgarn" [Knitted Fabrics of Paper Yarn], [10].

3. RESULTS

3.1 Handleability and knittability of the paper yarn

First knitting experiment
The first knitting experiment was performed on a Monarch Single Jersey machine; gauge E28 in plain knitting. The material was paper yarn in Nm 50/1 or in Nm 30/1 and the result showed defects in the fabric even if the yarn was treated with moisture before knitting. Also, another knitting experiment was done; with the same yarns and structure, on a Camber Velnit Single Jersey machine, gauge E18. Also, this attempt failed, with inaccuracies in the knitted fabric.

Second knitting experiment
For the second trial the Mayer & Cie Single Jersey machine, gauge E12 was used; specially build and equipped to knit stiff yarns such as metallic yarns, aramids or carbon fibres. The structure knitted was Piqué over four feeders (Piqué Lacoste). The fabrics compared in this second study are the same structures and are knitted on the same machine. The materials with yarn count Nm 50/1 and Nm 51/1 deviate because they are Single Jersey – plain fabric, knitted in the circular knitting machine Camber Velnit and therefore cannot be compared with the samples in Piké Lacoste binding. The plain fabric structure was made to investigate a highly prevalent fabric used in the fashion business.

The result was much better in the E12 machine; here it was much less or almost no damages or holes in the fabric. The tests showed that it is difficult to process paper yarns, especially in fine gauge knitting machines. In this experiment, on this machine, fabric samples in different materials and yarn counts were made for the pilling and shrinkage tests in this study (Table 2).

3.2 Pilling

The evaluation was done by the standard ASTM D3512 used to examine pilling of woven and knitted structures on a scale of 1-5 (Table 3).

Table 3. Pilling evaluation according to standard ASTM D3512.

Scale	5	4	3	2	1
Value	No pilling	Slight pilling	Moderate pilling	Severe pilling	Very severe pilling

After the first intervals 125, 500, 1000 and 2000, no difference could be seen. The test, therefore, continued to the next range of 5000 turns. During this interval, it could be detected that samples 3, 4, 5 had begun to rasing but no clear pilling yet. After 5000 turns the result showed as follows: Sample 3, 4, 5 and 6 all had pilling, and 9 and 10 still without pilling. After 7000 turns, the highest interval, the result indicated that sample 1, 8, 9 and 10 were without pilling as shown in Figure 1.

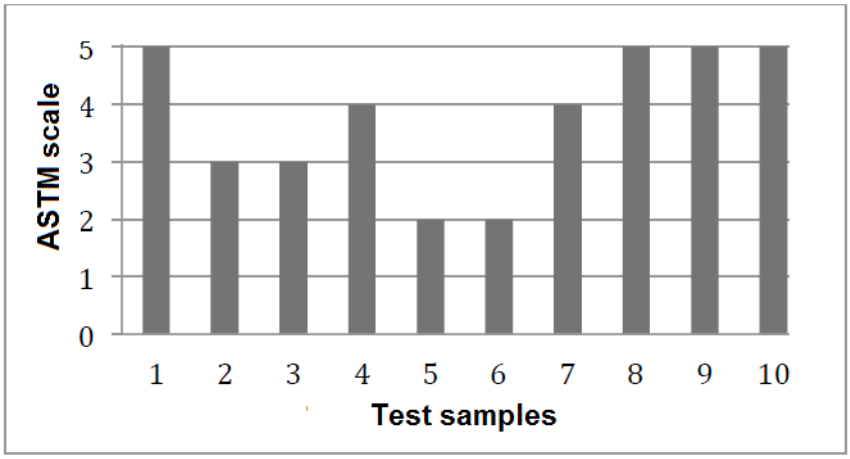

Figure 1. Pilling effect on the test samples after 7000 turns due to the ASTM D3512 scale.

In comparison between samples of different fibre materials, fabrics made of paper yarns showed the best results. No pilling was found in these samples compared with yarns of other materials. The cotton fabric showed the highest rate of pilling.

3.2 Dimensional change, shrinkage

Dimensional change – shrinkage: the best results of the yarns were showed by the paper yarn. This yarn had lowest results both in shrinkage and elongation with ≤ 5%. The samples were analysed according to the shrink-template specified in the standard method. The graph shows the change in dimension in length and width in the test samples, given in percentage. The sample that changed the most was sample 5; it was increased in the lengthwise direction and decreased in the width. Sample 6 was changed most in the percentage of all samples. Best results showed samples 1, 2, 9 and 10.

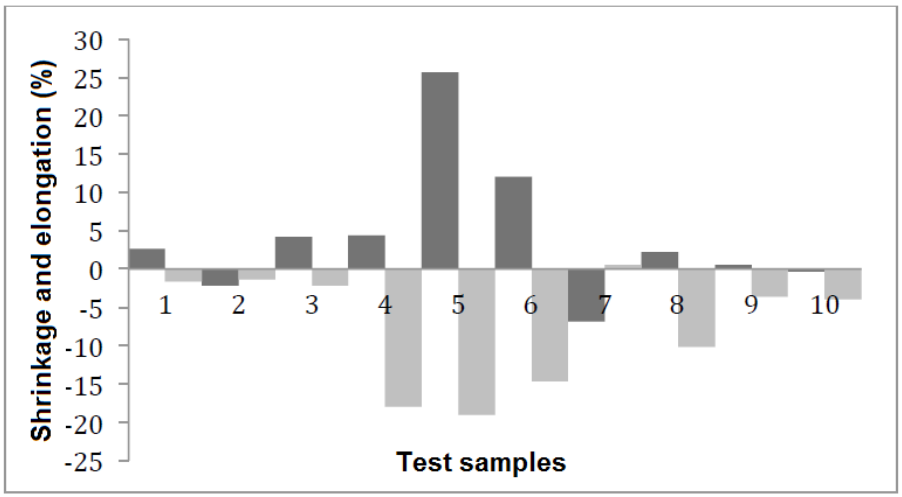

Figure 2. Dimensional change (mean value).

3.3 Tensile strength test of yarns

In the tensile strength test 14 different yarns in four fibre materials, paper, cotton, polyester and viscose as showed in Table 4. The yarn that was elongated (%) most in dry condition was sample number 7, polyester. Lowest rate of elongation (%) showed yarn number 4, paper yarn. The highest force at break exhibited paper yarns samples 1 and 2. Lowest force at the break had the cotton yarn, sample number 5.

Table 4. Tensile testing of yarn in dry condition (mean value).

Sample	Yarn	Force [cN]	Elongation [%]	Tenacity [cN/Tex]	Time at break [sec]
1.	Paper yarn Nm 30/1	561.921	4.608	16.859	2.8
2.	Paper yarn Nm 31/1	491.853	5.152	15.247	3.1
3.	Paper yarn Nm 50/1	269.550	3.407	13.478	1.9
4.	Paper yarn Nm 51/1	269.200	3.161	13,735	1.9
5.	Cotton Nm 61/1	196.918	4.978	12.012	3.0
6.	Viscose Nm 60/1	234.134	14.292	14.045	8.6
7.	Polyester Nm 68/1	419.578	16.698	28.531	10.0

The same tensile test with yarn in dry condition was performed in wet condition with the following results (Table 5). The yarn that was elongated (%) most in wet condition was sample number 14, polyester. Lowest rate of elongation (%) showed yarn number 8, paper yarn. The highest force at break exhibited paper yarns samples 8 and 9. Lowes force at the break had the viscose yarn, sample number 13.

Table 5. Tensile testing of yarn in wet condition (mean value).

Sample	Yarn	Force [cN]	Elongation [%]	Tenacity [cN/Tex]	Time at break [sec]
8.	Paper yarn Nm 30/1	546.132	6.498	16.386	3.9
9.	Paper yarn Nm 31/1	438.112	6.635	13.581	4.0
10.	Paper yarn Nm 50/1	273.998	6.993	13.700	4.2
11.	Paper yarn Nm 51/1	261.200	5.520	13.320	3.3
12.	Cotton Nm 61/1	262.671	7.321	16.026	4.4
13.	Viscose Nm 60/1	127.440	13.560	7.645	8.1
14.	Polyester Nm 68/1	381.969	16.024	25.967	9.6

4. DISCUSSION

The result of the knitting of the samples showed that the choice of machine gauge had a crucial role for the knittability. The machine must be able to knit the stiffer and more rigid paper yarn, compared with cotton, viscose or polyester that has a completely different manufacturing process and is gentle enough to be used in a variety of knitting machines and gauges. The difficulties in handleability / knittability of paper yarns can possibly be avoided by treating the yarn with paraffin, oil or moisture in some form before knitting.

Pilling was tested and the result showed no pilling, value 5 of the standard scale of pilling for fabrics manufactured of pure paper yarn without any other yarns involved. The reason for the fine pilling properties is probably because it´s made in a totally different way than the other yarns in the test.

Fabrics knitted of paper yarn all shows good properties, where the result demonstrated no significant shrinkage or elongation, as they were within five percent. The result exhibited that sample five changed most in percentage and it may depend on that material tangled together during the washing process.

Also in these tests, dry and wet tensile test the paper yarn showed good results. Braking force, elongation, and tenacity stand up well in competition with cotton, viscose and polyester. Not surprisingly polyester was the strongest yarn but paper yarn had a good strength also in wet condition.

5. CONCLUSIONS

What are the mechanical properties of paper yarn compared to conventional cotton, viscose, and polyester yarns? The handleability /knittability is a problem that has to be solved if the paper yarn is going to be used in the textile industry to a high extent in the future. Also, the high stiffness and hard grip of the paper yarn fabric must be solved. The results from the dimensional and pilling tests all show good results for the paper yarn compared with the reference samples. The paper yarn has low shrinkage and shows no tendencies to pilling, which are great characteristics for fabrics to be used in the textile- and clothing industry.

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EDITORIAL NOTE
This study is a part of a bachelor thesis in Textile Engineering at University of Borås, The Swedish School of Textiles 2015, title: “Trikå av pappersgarn” [Knitted Fabrics of Paper Yarn].

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