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RESEARCH

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Manufacture and physical properties of the denim fabrics using Hanji paper yarn as weft yarn

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Abstract

This study aims to develop the Hanji denim fabric with Hanji combination yarn or with the Hanji paper yarn and core spun yarn in a 1:1 ratio as a weft. For the weft yarn, chemical indigo and natural indigo dyestuffs were used. The study developed four kinds of Hanji paper yarns and eight kinds of Hanji denim fabrics. In addition, the study tested the properties of the developed Hanji paper yarns, Hanji denim fabrics, and existing denim fabrics. In regard to the physical properties of yarns, the Hanji paper yarn showed a lower breaking stress but a relatively high breaking strain, and it remained a stable structure with no surface fluff. The Hanji combination yarn improved the weaving ability and had a stable structure form. In the resulting physical properties of the developed Hanji denim fabrics, they had a low apparent specific gravity, stability in dimensional change in washing and drying, a higher chance of commercialization in colorfastness to washing, medium stretchability, a similar drying velocity, and a fast absorption velocity compared to the existing denim fabrics. The study suggests that the Hanji denim fabrics are the good candidate materials for summer product development, since generally the Hanji denim fabrics have cool characteristics with the excellent absorption velocity, drying velocity, and low specific gravity.

Keywords: Hanji paper yarn, Combination yarn, Hanji denim fabrics, Physical properties

Introduction

A denim fabric is defined as a 100% woven cotton or union cloth with the ratios of 2:1 or 3:1 twill tissue using a warp, 7–20 Ne of cotton yarn (indigo vat dyeing), and the weft, unbleached yarn of 10–15 Ne. A surface of the denim fabric shows a blue color while the inside color shows a white color family only. Recently, the blue series production has been complimented by other colors with weaving patterns becoming more varied. Presently, the denim fabric is not limited to denim jean pants but also is widely used among those of all ages and genders of adult wear and children's wear (Kim et al. 2009). In addition, the denim fabric is used in various other applications.

Human skin has an ability to stretch greatly with body movements. Generally, a wearer also expects to see the same attitude from their clothing (Ozdil 2008). However, the denim fabric is wrinkled since it does not have stretchable fiber component. It is a heavy weight fabric compared to other woven fabrics. Instead of using the unbleached weft roll, one way to give successful stretchability to the denim fabric as a way to prevent wrinkles, is by the use of cotton yarn and spandex yarn by turns or, a second way, is by using a cotton/polyester blended spun yarn. However, even though the denim fabric that used cotton yarn and spandex yarn by turns has a relatively good stretchability, there have been issues due to the denim fabric's uneven surface because the spandex yarn is of a fine sized yarn compared to the cotton yarn. In addition, in the case of the cotton/polyester blended spun yarn, it has been found that stretch and fabric lightweight improvement is needed to meet consumers' needs. Recently, a core spun yarn is used as the weft yarn in order to give the denim fabric stretch (Ozdil 2008). The core spun yarn has stretchability with a feel of cotton because it has spandex as its core yarn and it is wrapped by cotton yarn.

Since the denim fabric is stiff and the color of indigo blue fades over time, without an application of finishing methods by either conventional industrial washing or new laser fading, it is not easy to achieve high quality denim wear (Juciene et al. 2006; Kan and Wong 2011; Khedher et al. 2011). In the world today, the premium denim fabric's dye has been known as a dye that gradually and slightly fades with repeated washings and with a dehydration process. Also, there is need for comfort with softer touch, a lighter weight, and stretch to this premium fabric. With this trend, recently, there has been a development of functional denim fabrics. For example, in Japan in 2015, a paper denim fabric has been developed and used as the premium denim fabric (Park and Lee 2016). This denim fabric has received attention as it introduces the need for lightweight with improved comfort by using a cotton yarn (indigo rope-dyeing) as the warp, and the Japanese paper yarn as the weft. The Japanese paper denim fabric is proper for denim jean pants and/or shirts worn in warm summer months. However, problems exist with wrinkles due to the fabric's high rigidity and low stretchability of the paper yarn. In addition, there are consumers who want to wear denim jean pants or denim shirts, but they have a tendency to avoid these denim products due to skin allergies that are caused by a reaction to a chemical dye in the denim fabric.

In the production of the paper yarn, a Hanji paper yarn is produced in almost the same process system as Japanese paper yarn, so the properties of the two paper yarns are quiet similar (Kim et al. 2006; Kim and Park 2008; Itoi 2001; Ishikawa and Shinohara 2001). In Korea, the Hanji paper yarn is made of Hanji paper sheets, so it has a high bulkiness. The thickness of paper yarn is greater than that of the same count of cotton yarn. As a result, the Hanji paper yarn is evaluated as a lightweight yarn because Hanji paper yarn's diameter is larger meaning that the apparent specific gravity is lower (Kim et al. 2007; Park 2012). Therefore, it is possible to produce a lightweight denim fabric that actually feels lighter when worn by using the Hanji paper yarn as the weft. This is because the Hanji paper yarn is a paper yarn and is lightweight by its characteristic of yarn structure and is fast in absorption rate and drying speed rates. Therefore, Hanji denim fabric is a lightweight fabric material with a low specific gravity compared to existing denim fabric resulting in having excellent form stability and comfort.

On the other hand, the core spun yarn used to impart elasticity to fabrics and their usage has recently been increasing. Most significantly, in the production of denim fabrics when the core spun yarn and the paper yarn are used properly as weft, it is found that the disadvantages of the paper denim fabric's heaviness, roughness, and wrinkles caused by low stretchability, can be greatly improved.

In general, yarn count of the weft for commonly used cotton denim fabrics in summer and winter are respectively about 15 and 10 Ne. Taking this into consideration when calculating the count of final Hanji combination yarn, a single paper yarn count of the summer and winter usage is appropriate with the count of 30 and 15 Ne respectively based on the core spun yarns 30 Ne. Thus, when weaving with the paper yarn and the core spun yarn in the weaving process, according to the season, it is also advised to select each weft yarn within a similar yarn count range compared to the preferred cotton yarn count.

Therefore, in this study, we aim to manufacture the Hanji denim fabric by using either of these two yarn types for the weft: of the Hanji combination yarn (combined Hanji paper yarn with core spun yarn) or by inserting the Hanji paper yarn and the core spun yarn in a 1:1 ratio. In the warp, we plan to use two kinds of existing yarns dyed with a chemical indigo dyestuff and a natural indigo dyestuff (blue color). After manufacturing Hanji denim fabrics, we plan to test the properties of the developed Hanji denim fabrics and the existing denim fabrics to compare them. This study also plans to suggest commercialization of denim fabric products utilizing the Hanji denim fabrics that have the improved properties such as light fabric weight, stretch, and comfort.

Methods

Manufacturing of Hanji paper yarn and combination yarn

The paper yarns used in the weft were made into two types, single yarn and combination yarn. First, in the manufacturing process of a single yarn, a paper sheet was cut to a pre-determined width to make a tape yarn, and after that the single yarn was produced by adding a proper twist to the tape yarn through a twisting machine. In other words, the Hanji paper sheet, with the weight of 13 g/m^2, was cut into the tape yarn in the width of 2.75 and 3.75 mm. Then, the Hanji paper yarns, count of 16 and 11 Ne, were produced after twisting 600 and 520 tpm (Z-twist), respectively, using a twisting machine (Murata® 363). The combination yarn was manufactured by combining paper yarn and core spun yarn. In this study, Hanji paper yarn of 16 or 30 Ne was plied in S-twist with the core spun yarn [cotton (sheath)/spandex (core)]. After that, the structures of Hanji combination yarns were stabilized through the steam setting for 14 min at 105 °C. With this process, the count of Hanji combination yarn produced was 10 and 15 Ne, respectively.

Manufacturing of Hanji denim fabrics

Table 1 shows the specifications of Hanji denim fabrics. Denim fabrics were woven in twill (3/1) using an air jet loom (TOYOTA®, JA4SF) and the weft (Hanji paper yarn and combination yarn) inserting speed was approximately 560–570 rpm. The warp was used in two types of cottons: a cotton yarn (8 Ne) dyed with chemical vat dyestuff and a cotton yarn (10 Ne) dyed with natural vat dyestuff (indigo). Four kinds of weft were used so that eight kinds of denim fabrics were produced. For weaving of the denim fabrics, the combination yarns were singly inserted, while the single yarns and core spun yarns were inserted in a 1:1 ratio. Raw materials were produced through the process of singeing,

Table 1 Specifications of Hanji denim fabrics

Sample code (denim fabric)	Yarn specification (abbreviation)		Fabric density (warp × weft per inch)	
	Warp	Weft	Raw fabric	Finished fabric
DF1 (C8)	Rope-dyed cotton yarn (8 Ne; CY8)	Combination yarn (10 Ne; COY10): [Hanji paper yarn (16 Ne)/core spun yarn (30 Ne)]	67 × 52	73 × 55
DF2 (C8)		Combination yarn (15 Ne; COY15) [Hanji paper yarn (30 Ne)/core spun yarn (30 Ne)]	66 × 55	75 × 61
DF3 (C8)		Hanji paper yarn (11 Ne; HPY11) + core spun yarn (10 Ne; CSY10)	66 × 46	75 × 52
DF4 (C8)		Hanji paper yarn (16 Ne; HPY16) + core spun yarn (16 Ne; CSY16)	66 × 43	77 × 55
DF1 (C10)	Cheese-dyed cotton yarn (10 Ne; CY10)	Combination yarn (10 Ne; COY10): [Hanji paper yarn (16 Ne)/core spun yarn (30 Ne)]	69 × 53	75 × 56
DF2 (C10)		Combination yarn (15 Ne; COY15) [Hanji paper yarn (30 Ne)/core spun yarn (30 Ne)]	69 × 55	79 × 60
DF3 (C10)		Hanji paper yarn (11 Ne; HPY11) + core spun yarn (10 Ne; CSY10)	69 × 52	78 × 56
DF4 (C10)		Hanji paper yarn (16 Ne; HPY16) + core spun yarn (16 Ne; CSY16)	70 × 56	83 × 60
S1 (Stretch)	Cotton yarn	Cotton yarn + core spun yarn	–	67 × 50
S2 (Stretch)	Cotton yarn	Core spun yarn	–	82 × 67

desizing, laundry (shrink-proof), and tenter process. Table 1 shows the material specifications of Hanji denim fabrics and existing denim fabrics (S1, S2) in the market.

Evaluation of properties of Hanji paper yarn and its woven fabric

The tensile properties and yarn count of the Hanji single yarn and combination yarn were measured according to KSK ISO 2062 and KSK ISO 2060 (Skein method) respectively. The colorfastness to washing and the dimensional change in washing and drying of the fabric were measured by KSK ISO 105-C06 (A2S) and KSK ISO 5077, respectively. The elastic recovery and colorfastness to light were measured by KSK 0352 and KSK ISO 105-B02 (Xenon arc). Drying velocity and absorption velocity were measured by KSK 0815 (6.28.1-A) and KSK 0815 (6.27.1-B), respectively. The surface structures of Hanji paper yarns and combination yarns were observed by scanning electron microscopy (SEM) and those of Hanji denim fabrics were measured by a video microscope system (Sometech Inc.). Fabric specific gravity was determined by mass per unit volume commonly expressed, in grams per cubic centimeter.

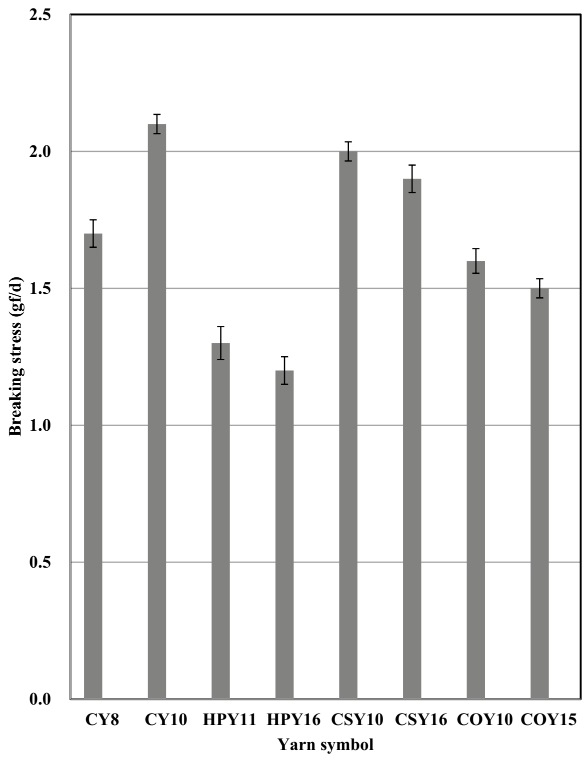


Fig. 1 Breaking stress of warp and weft yarn used for Hanji denim fabrics

Results and discussion

Physical properties of yarns

Figures 1 and 2 present the tensile properties of the warp and weft yarn used to develop Hanji denim fabrics. The breaking stress of Hanji paper yarn was lower than those of cotton yarn and core spun yarn, but the paper yarn maintained relatively high breaking strain. Since the Hanji combination yarn was obtained by doubling and twisting the structure of Hanji paper yarn and core spun yarn, the weaving ability was made more complimentary by the increased tensile strength of Hanji paper yarn. Empirically, when the paper yarn is used as the weft yarn, it is known that reducing the weft inserting speed slightly prevents yarn breakage since the paper yarn has a lower breaking stress than that of the same count of cotton yarn.

Figure 3 shows the surface structure of the warp and weft yarn used in this study. Two types of warp (cotton yarn) were used, 8 and 10 Ne, respectively. The former was a rope-dyed cotton yarn and the latter was a cheese-dyed cotton yarn. In the surface structure of the yarns, the rope-dyed cotton yarn showed a rather bulky structure and the cheese-dyed cotton yarn showed a compact structure.

On the other hand, for the denim fabrics, the Hanji paper single yarn, core spun yarn, and Hanji combination yarn were used as the weft. As shown in Fig. 3, the twisted shape of Hanji paper yarn showed a stable structure with little fluff on the surface unlike that of cotton yarn. The core spun yarn had a slightly bulky structure because the cotton yarn enveloped a spandex filament (core yarn). In the existing denim fabrics, the use of core spun yarn as the weft began with the development of skinny denim products in recent

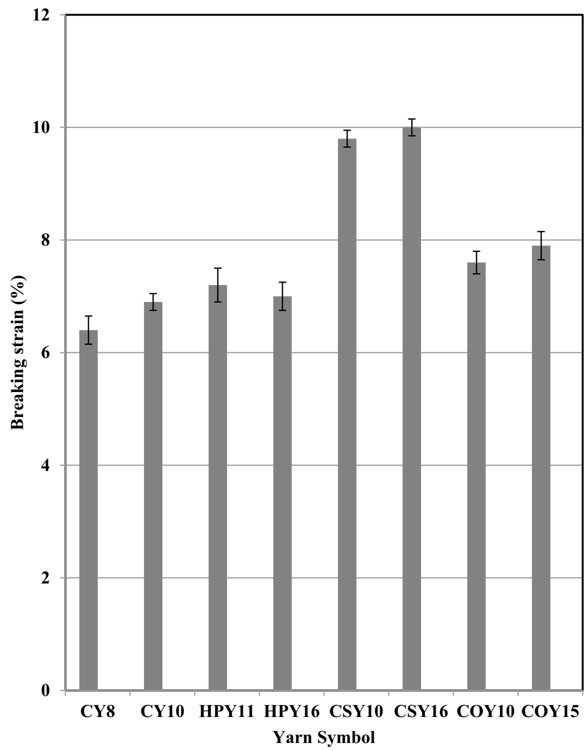


Fig. 2 Breaking strain of warp and weft yarn used for Hanji denim fabrics

years, and core spun yarns were commonly used to improve the surface properties of core yarns and to produce stretch fabrics. Also, the structure of Hanji combination yarns showed that two kinds of yarns, the Hanji single yarn and the core spun yarn, were combined in a stable form.

The study evaluated the optimal weft inserting speed with two cases using Hanji combination yarn alone and Hanji paper yarn and core spun yarn in a 1:1 ratio. As a result, the optimal weft inserting speed (approximately 620 rpm) for the Hanji paper yarn was approximately 90% of the cotton yarn with the same yarn count. This is because we believe the tensile strength of Hanji paper yarn and Hanji combination yarn is lower than that of ordinary cotton yarn.

Figure 4 shows the surface structure of the Hanji denim fabrics. The denim fabrics of DF1 (C10) to DF4 (C10) had some natural vat dyestuff (indigo) come off in the processing and the dyestuff migrated into the weft yarn so that warp and weft yarns were not clearly distinguishable resulting in slightly lowering the colorfastness to washing. However, in general, the appearance of most of Hanji denim fabrics developed through the study seemed favorable and there was not a significant difference from the existing denim fabrics (S1 and S2) which were commercialized.

Physical properties of Hanji denim fabrics

As shown in Table 1 and Fig. 5, due to the shrinkage in finishing process, the finished fabric density increased significantly compared to the raw fabric. Most of the produced denim fabrics showed less than ±5% change in the dimensional change in washing and

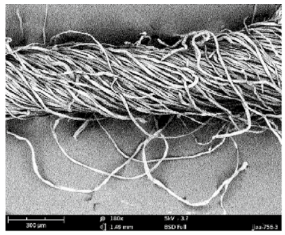
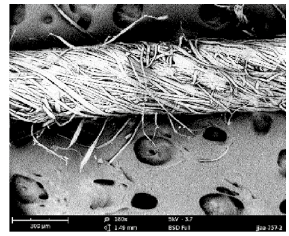
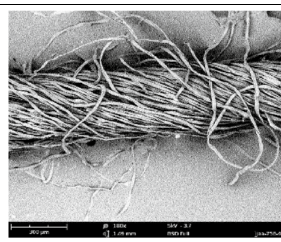
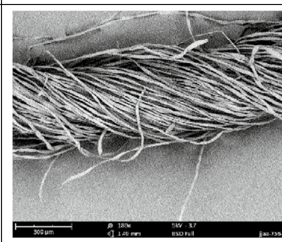
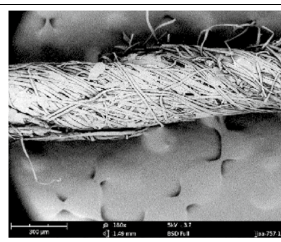
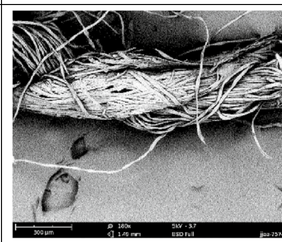
Sample code	Surface structure	Sample code	Surface structure
CY8		HPY16	
CY10		CSY16	
HPY11		COY16	

Fig. 3 SEM micrographs of the surface structure of warp and weft yarn

drying, which means commercialization of Hanji denim fabrics is possible. Overall, the denim fabric with rope-dyed yarn had a lower dimensional change than the fabric with cheese-dyed yarn, which indicated the rope-dyed yarn denim fabric had better dimensional stability. Therefore, it is suggested that the denim fabrics using cheese-dyed yarn are needed another separate treatment, such as a sanforizing finish to prevent fabric shrinkage. Also, in the same denim fabrics, the Hanji denim that used the Hanji combination yarn as the weft was higher in dimensional change in washing and drying than that of the Hanji denim that used Hanji single yarn and the core spun yarn in a 1:1 ratio.

Table 2 shows the specific gravity, colorfastness, and elastic recovery rate of Hanji denim fabrics. Generally, in fabrics of the same weight, the characteristics of the fabrics where consumers can experience its lighter weight and the light feeling of wearing are very important to the consumers. In the study, the apparent specific gravity of the Hanji denim fabrics (0.471–0.539) produced in this study was lower than that of the existing denim fabrics (0.567–0.577), so the lighter weight can be easily noticed when worn. This seemed to be due to the large thickness and bulky structure of the Hanji paper yarn compared to the same yarn count of cotton yarn. Importantly, the denim fabric with rope-dyed yarn on the warp showed a lower apparent specific gravity than that of fabric with the cheese-dyed yarn, resulting in a lighter wearing weight. In other words, in the cheese-dyeing process, since winding and unwinding tension from the dyeing bobbin was high, the yarn became less bulky and a smoother structure was obtained.

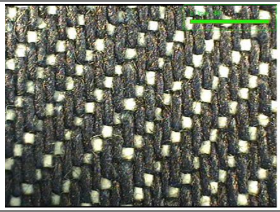
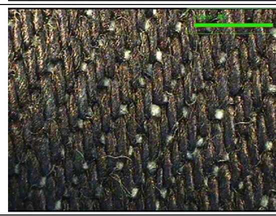
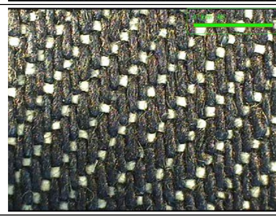
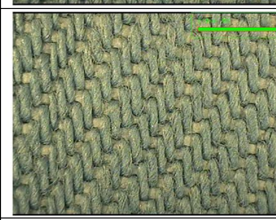
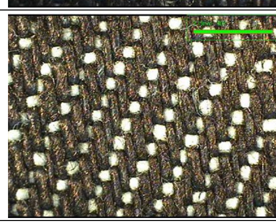
Sample code (Denim fabric)	Surface structure	Sample code (Denim fabric)	Surface structure
DF1(C8)		DF1(C10)	
DF2(C8)		DF2(C10)	
DF3(C8)		DF3(C10)	
DF4(C8)		DF4(C10)	
S1		S2	

Fig. 4 Photographs of the surface structure of Hanji denim fabrics (× 40)

The colorfastness to washing (color change and staining) showed a higher chance of commercialization in all manufactured and existing commercial denim fabrics. However, the results of colorfastness to light showed differently; the colorfastness of the denim fabrics that used the chemical dyestuff as the warp yarn was four grades above while that of the denim fabric that used the natural dyestuff was graded as grade 3 or grade 3–4. When compared with the existing denim fabric products (S1, S2), the developed denim fabrics using synthetic dyestuff as the warp yarn seemed to have no problem in merchandising. On the other hand, the colorfastness to light of the indigo natural dyestuff was lower than the chemical dyestuff, which indicated the stability against daylight was slightly lower. However, considering that denim fabric products such as jean pants and jean jackets were recognized as premium denim fabrics in which the indigo

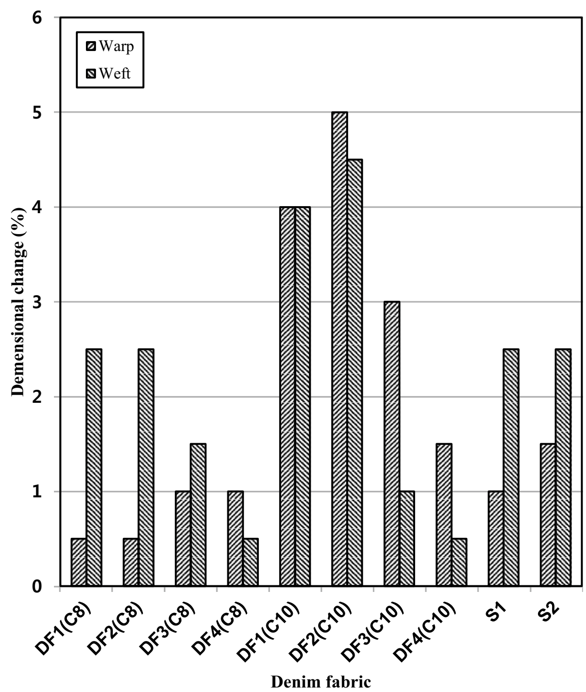


Fig. 5 Dimensional change in washing and drying of Hanji denim fabrics

Table 2 Specific gravity, colorfastness, and elastic recovery rate of Hanji denim fabrics

Sample code (denim fabric)	Weight (g/m^2)	Thickness (mm)	Specific gravity	Colorfastness to washing (grade)		Colorfastness to light (grade)	Elastic recovery rate (%)	
				Color change	Staining		Warp	Weft
DF1 (C8)	375	0.74	0.507	4–5	4–5	Above 4	54	77
DF2 (C8)	349	0.69	0.506	4–5	4–5	Above 4	56	75
DF3 (C8)	385	0.76	0.507	4–5	4–5	Above 4	52	78
DF4 (C8)	367	0.78	0.471	4–5	4–5	Above 4	69	75
DF1 (C10)	361	0.67	0.539	4–5	4–5	3–4	38	41
DF2 (C10)	320	0.63	0.508	4–5	4–5	3–4	44	56
DF3 (C10)	358	0.68	0.526	4–5	4–5	3–4	52	71
DF4 (C10)	361	0.68	0.531	4–5	4–5	3	54	70
S1	380	0.67	0.567	4–5	4	Above 4	50	70
S2	352	0.61	0.577	4–5	4–5	Above 4	67	79

dyes gradually disappear in the course of repeated washing and dehydration, we believe that the denim fabric using the natural dyestuff as the warp is able to commercialize sufficiently.

For the elastic recovery rate of Hanji denim fabrics developed in the study, we compared the result with that of existing stretch denim fabrics (S1, S2). Basically, the standard denim fabrics are made of unbleached cotton yarn, so there is no elasticity and many wrinkles. Recently, denim fabrics have been given elasticity according to consumers' needs. The existing denim fabrics, which were compared with the Hanji denim fabric

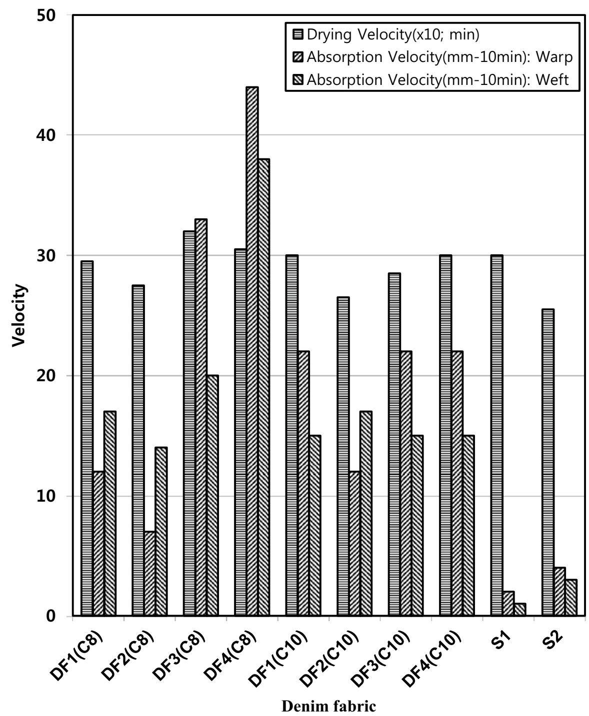


Fig. 6 Drying velocity and absorption velocity of Hanji denim fabrics

produced in this study, were denim fabrics with medium stretch (S1) and high stretch (S2). The approximate structure of the existing denim fabrics (S1, S2), using the analysis of fabric structure, showed cotton yarns (navy color) and stretch yarns used as warp and weft, respectively. Most Hanji denim fabrics produced, except for the DF1 (C10) and the DF2 (C10), showed a higher elastic recovery rate than that of existing medium stretch denim fabric (S1). The high recovery rate trend resulted mainly in the denim fabrics using the rope-dyed yarn.

Figure 6 shows the drying velocity and absorption velocity of Hanji denim fabrics. The drying velocity of Hanji denim fabrics increased as the fabric's weight increased. This resulted because as the weight increases, the hydrophilic fiber of the fabric absorbs a large amount of moisture, leading to a longer drying time. Also, the existing denim fabrics showed a similar tendency, and compared with Hanji yarn denim fabrics, the drying speed of the existing denim fabrics was almost the same (or slightly faster). On the other hand, the absorption velocity of Hanji denim fabrics showed significant differences. The Hanji denim fabric dried much faster than those of existing denim fabrics. This tendency is due to the high absorbency of Hanji yarn compared to cotton yarn. Especially, the tendency with Hanji yarn and core yarn with a 1:1 ratio showed a higher absorption velocity than that of the cotton yarn. Overall, the Hanji denim fabrics showed a higher absorption velocity than those of the existing denim fabrics (S1, S2). In addition, there was no significant difference in the drying velocity between the Hanji denim fabric and the existing denim fabrics even though the Hanji denim fabrics absorb more moisture compared to the existing denim fabrics.

Fig. 7 Denim wear products using manufactured Hanji denim fabrics

Therefore, it was considered that Hanji denim fabrics are suitable for summer use product development considering that general Hanji fabrics have pleasant cooling characteristics in addition to the excellent absorption velocity and drying velocity. This is because the Hanji yarn developed and used in this study is a paper yarn composed of mulberry and manila hemp fiber. The characteristics of fiber and structure of this paper yarn give its cooling characteristics to Hanji denim fabrics. Figure 7 shows design applications in jean pants, shirts, and dresses that were manufactured using the Hanji paper denim fabric developed in this study. It showed no difference compared to the existing denim fabric (cotton fabric) in the process of fabric cutting, sewing, and its wearability.

Conclusions

With the popular use of denim fabric and of the advantages of paper yarns, we aimed to develop the Hanji denim fabric with Hanji combination yarn or with the Hanji paper yarn and core spun yarn in a 1:1 ratio as the weft. As the warp yarn, chemical vat and natural dyestuffs were used. We tested the properties of the developed Hanji paper yarns, combination yarns, and Hanji denim fabrics. The summary and conclusions are as follows.

With regard to the physical properties of yarns, the breaking stress of Hanji paper yarn was lower than those of the cotton yarn and the core spun yarn, but the paper yarn maintained a relatively high breaking strain. The Hanji combination yarn has been improved the weaving ability by complementing the tensile strength of Hanji paper yarn. In the surface structure of the yarn, the rope-dyed cotton yarn showed a rather bulky structure while the cheese-dyed cotton yarn showed a compact structure. The structure of Hanji combination yarns showed that the Hanji single yarn and core spun yarn were tightly combined resulting in a stable form. The optimal weft inserting speed for the Hanji paper yarn was approximately 90% of the cotton yarn with the same yarn count. Also, the appearance of most Hanji denim fabrics produced showed no significant difference from the existing stretchable denim fabrics indicating commercialization of Hanji denim fabrics as highly possible.

With regard to the physical properties of developed denim fabrics, the apparent specific gravity of the Hanji denim fabrics produced was lower than that of the existing denim fabrics, so garments when worn could feel light. The dimensional change in washing and drying: the rope-dyed yarn denim fabrics showed better dimensional stability than the fabrics with cheese-dyed yarns. The colorfastness to washing showed a higher chance of commercialization in all manufactured and existing commercial denim fabrics. The colorfastness to light, the developed denim fabrics using synthetic dyestuff as the warp yarn seemed to have no problem in merchandising while the stability against daylight of natural dyestuff was slightly lower. The elongation recovery rate of Hanji denim fabrics showed that most developed Hanji denim fabrics had a similar elongation recovery rate to the existing denim fabrics that had medium stretchability (S1). The drying velocity of Hanji denim fabrics showed a tendency to increase with increasing fabric weight while the absorption velocity of Hanji denim fabrics showed significant differences: Hanji denim fabric was much faster to dry than those of existing denim fabrics.

Through the study, we found that the developed Hanji denim fabrics had several advantages compare to the existing denim fabrics. It has a low apparent specific gravity due to it being a paper yarn while it has a dimensional stability. Further, there is a higher chance of commercialization in colorfastness to washing with a medium stretchability. Lastly, a drying velocity is a similar to existing denim fabrics while an absorption velocity is fast in comparison to that of existing denim fabrics.

Therefore, the study suggests that the Hanji denim fabric is a good fabric for summer product development usage such as jean pants, jean skirts, and jean shirts since it generally has many pleasant cooling characteristics in addition to the excellent absorption velocity with a lower fabric weight for comfortable wearing. Through this study, we hope that the Hanji denim fabrics contribute to meet consumers' needs who have concerns in healthcare issues and in environmental issues. This new fabric creates a new interest on the market development making it a high value-added business.

Authors' contributions

Both TYP and MOK carried out the literature review and the research frame work. TYP conducted experiments and drafted the manuscript. MOK developed denim design experiments and result analysis. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable.

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