(REFEREED RESEARCH)

EVALUATION OF DRAPE, BENDING AND FORMABILITY OF WOVEN FABRICS MADE FROM METAL COVERED HYBRID YARNS

METAL KAPLI HİBRİD İPLİK İÇEREN DOKUMA KUMAŞLARIN DÖKÜMLÜLÜK, EĞİLME VE ŞEKİL VERİLEBİLME ÖZELLİKLERİNİN İNCELENMESİ

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ABSTRACT

The novel textile structures including yarns with metal fibres or filaments have been investigated in terms of functionality, but not in terms of their ability to be manufactured into a garment. In this study, these novel structures were evaluated from the point of view of tailorability and fit. For this purpose, bending rigidity, formability and drape coefficient of woven fabrics produced from metal covered hybrid yarns in different weaves were measured and compared with the fabrics woven without metal wire. The results of these parameters and their relationships were assessed statistically with the explanations of their influence on tailorability and fit. The results confirmed quantitatively that these structures could provide better fit and tailorability when they were applied as a layer into a garment rather than being used in the whole garment production.

Keywords: Cotton yarn, hybrid yarn, metal wire, woven fabric, drape coefficient, bending rigidity, formability, tailorability, fit.

ÖZET

Metal lif ya da filament içeren ipliklerden oluşan yeni tekstil yapıları fonksiyonellik açısından değerlendirilmiş olmakla birlikte giysi üretiminde kullanılabilirlikleri açısından incelenmemiştir. Bu çalışmada, bu yeni yapılar, kumaşın beden şekline göre dikilebilme ve vücuda uygunluğu açısından değerlendirilmiştir. Bu amaçla, metal kaplı hibrid iplikler kullanılarak farklı örgü tiplerinde dokunan kumaşların eğilme rijitliği, şekil verilebilirlik ve dökümlülük katsayıları ölçülmüş ve metal kaplı hibrid iplik içermeyen dokuma kumaşlar ile karşılaştırılmıştır. Ölçülen bu parametrelere ait sonuçlar ve bu parametreler arasındaki ilişkiler istatistiksel olarak değerlendirilmiş ve söz konusu parametrelerin dikilebilme ve vücuda uygunluk üzerideki etkileri açıklanmıştır. Elde edilen sonuçlar, bu tip yapıların giysinin bütününde kullanılmasından ziyade bir katman olarak giysi yapısına katıldığında dikilebilirlik ve vücuda uygunluk açısından daha iyi sonuçlar vereceğini kantitatif olarak doğrulamıştır.

Anahtar Kelimeler: Pamuk ipliği, hibrid iplik, metal tel, dokuma kumaş, dökümlülük katsayısı, eğilme rijitliği, şekil verilebilirlik, dikilebilirlik, vücuda uygunluk.

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1. INTRODUCTION

Yarns including metal fibres or filaments have gained importance for obtaining anti-static and electromagnetic interference shielding properties as well as electrostatic protection, signal transfer and monitoring due to the increase in the use of electrical and electronic equipments in both household and non-household applications [1, 2]. The main focus of the studies regarding yarns containing metal fibres or filaments has been the evaluation of their functionality in terms of electrical conductivity, electromagnetic and electrostatic shielding properties [3-17]. Besides, physical performances of the metal containing yarns and fabrics, such as hairiness, tensile and tear strength, seam slippage, dimensional stability, pilling propensity, abrasion resistance, as well as colour and whiteness properties were investigated [16-22]. In addition, Ortlek et al [15] investigated thermal comfort properties of single jersey fabrics produced from hybrid yarns containing metal wire, and Ceven et al [23] investigated the air permeability of cotton woven fabrics containing metal.

The fabrics containing metal yarns are used in garments for obtaining electromagnetic shielding, antistatic and shape memorizing properties. They are generally used in protective clothing for people who directly expose to electromagnetic wave in working areas. Other than protective clothing, protection of human body against electromagnetic waves in daily life is the emerging area of application of such types of fabrics in garments including lining fabrics for pockets and jackets especially for people with pacemakers, underwear, outerwear such as shirts, blouses and jackets [24]. Nevertheless, a review of the literature revealed that little research has evaluated the behaviour and properties of such novel structures that are important for predicting their ability to be manufactured into a garment, i.e. tailorability, and their fitting gracefully on human body. So far, bending rigidity of core and wrapped yarns containing metal wire as well as bending rigidity of woven fabrics made from hybrid yarns containing stainless steel wires have been evaluated [17, 21]. Moreover, drape behaviour, crease recovery and bending properties of copper core yarn, stainless steel core yarn, glass core yarn, and copper ply yarn woven fabrics have been investigated [25]. However, none of the studies have investigated the bending properties, formability and drapeability of these fabrics from the point of view of tailorability and fit of the garment.

The bending length is a characteristic property of a woven fabric and is dependent upon the energy required to produce a given bending deformation under its own weight. The bending length, the bending rigidity, which is derived from the bending length, and the weight of the fabric form the bending properties of the fabrics that influence the mechanism of fabric deformation [25]. The anisotropy of the fabrics causes considerable fabric deformation even at low loads, and this deformation is important for tailoring, as well as fitting a garment [26]. While the fabrics with relatively high values of bending rigidity do not generally cause problems in handling during garment manufacturing, low bending rigidity may cause distortion during cutting, seam puckering during sewing, and poor shape retention, e.g. sagging, which interrupts properly fitting [27, 28].

Formability is a measure of ability of a fabric to absorb compression in its own plane without buckling. It is essential for a smooth garment manufacturing process, and used as a direct indicator of likelihood of seam puckering during sewing. Formability signifies the conformant of a particular shape during tailoring, which is achieved by forcing a 2D fabric to take a 3D shape [28, 29].

Drape is defined as the extent to which a fabric will deform when it is allowed to hang under its own weight [30]; and drape coefficient (DC) is used as the measure of drape, which provides an objective description of drape deformation in three dimensions [29]. Affecting the dynamic functionality of fabrics, drape enables determining the adjustment of a garment to the human silhouette [31].

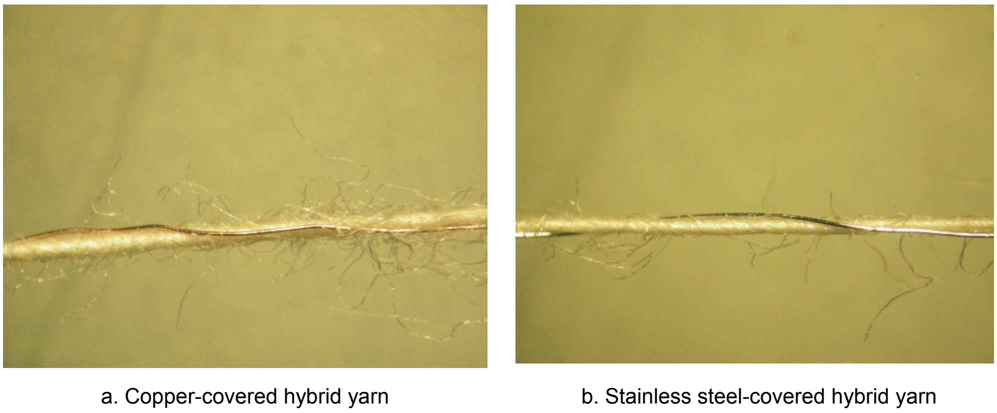
Both fabric drapeability and formability is dependent on fabric bending rigidity; since it governs the behaviour of fabric when a change is caused in the direction of yarns by bending deformation [29]. Thus, for evaluating the usability of novel structures in garment making in terms of tailorability and fit, these properties as well as their relations have to be taken into consideration at the same time.

Recognizing the need for studying in this area, the main purpose of this study is to evaluate the bending rigidity, formability and drapeability, and their relationships for the woven fabrics with different weave structures produced from yarns including metal wire. The relationships between the measured characteristics were assessed using statistical analysis, and the results were discussed regarding tailorability and fit.

2. MATERIALS AND METHOD

In this study, 30/2 Ne cotton yarn was used as warp yarn, and metal covered hybrid yarns and plied cotton yarn were used as weft yarns. 20/1 Ne cotton yarn with twist coefficient of α_e 4.03 (710 TPM-turns per meter- in Z direction) was wrapped with copper and stainless steel wires in diameter of 0.05 mm by using Agteks DirecTwist Machine. Since the counts of copper-covered and stainless steel-covered hybrid yarns were obtained as 11.6 Ne and 12.6 Ne respectively, 20/1 Ne cotton weft yarn in the sample without metal wire was also plied on Agteks DirecTwist Machine in order to obtain comparable samples in terms of yarn count.

Single yarns are generally ply-twisted in the direction opposite to single yarn twist in order to remove the torque on the yarn and obtain a balanced yarn [32]. Therefore; plied cotton yarn was twisted in S direction. On the other hand, metal wires were wrapped in Z direction in order to avoid possible yarn breaks due to untwisting of single cotton yarn during ply-twisting. The pictures of the metal-covered yarn samples are shown in Figure 1.



a. Copper-covered hybrid yarn

b. Stainless steel-covered hybrid yarn

Figure 1. Pictures of metal-covered yarn samples.

Fabric samples were produced on a CCI sampling loom. The specifications of the weft yarns used in fabric sample production are given in Table 1. The yarn counts of metal covered hybrid yarns and plied cotton yarns were determined according to TS 244 EN ISO 2060 standard [33]. The breaking elongation values of cotton yarn used as core material, copper wire and stainless steel wire were measured by using Titan universal strength tester according to TS EN ISO 2062 [34]. The bending rigidities of the yarns were determined by ring-loop method proposed by Peirce in 1930 [35].

The specifications of the fabric samples are listed in Table 2. Number of warp and weft yarns per cm, fabric weight and thickness of the fabric samples were determined according to TS 250 EN 1049-2, TS 251 and TS 7128 EN ISO 5084 standards respectively [36-38].

Bending length of the fabric samples in warp and weft directions were measured by using FAST-2 bending meter in order to determine the bending rigidity of the fabric samples in these directions. The bending rigidity (B) was calculated in warp and weft directions as:

$$B = W \, x \, c^3 \, x \, 9.81 \, x \, 10^{-6} \quad (1)$$

where,
W: fabric weight, g/m^2
c: bending length, mm

The resistance of the fabric samples to bending in multiple directions was determined by using circular bending rigidity tester. In circular bending rigidity tester, a plunger forces a flat, folded specimen of fabric through a circular orifice in a platform. The maximum force (measured in N) required to push the fabric through the orifice is considered as an indication of the resistance to bending [39, 40].

The formability of the fabric samples were calculated as the product of calculated bending rigidity and the extensibility of the fabric at low loads, e.g. 5 gf/cm and 20 gf/cm obtained from the measurements in FAST-3 extension meter, using equation 2:

where, the formability is expressed in mm, the bending rigidity in μNm and extension in percentage [41].

The drapeability of the fabric samples were evaluated by cut and weigh method. For determination of drape coefficients, circular specimens were prepared and held between two supporting discs; which allowed them to drape into folds under their own weights. The shadows of the specimens were traced onto a piece of paper ring at the same size as the unsupported part of the fabric specimen. First, the whole paper ring was weighed and then the shadow part of the ring was cut away and weighed. The drape coefficient was calculated using the following equation [42]:

All tests were carried out under standard atmospheric conditions, i.e. 20±2 °C temperature and 65±4 % relative humidity. The samples were conditioned for a minimum 24 hours before tests. Independent samples t-test, analysis of variance (ANOVA) and post hoc tests were used to analyze the test results for significance in differences of the mean values of the measured properties, and correlation analysis was used to define the relationships between the measured properties in SPSS 21 [43].

Table 1. Specifications of weft yarns.

Yarn code for plied yarns	Weft yarn								Bending rigidity (gcm)
	Core material		Wire			Ply twist		Plied yarn count	
	Count (Ne)	Fiber type	Diameter (mm)	Type	Elongation at break (%)	TPM	Direction	Ne	
Co-Co	20/1	Cotton	No wire		7,34	350	S	10.0	3.22
Co-Cu	20/1	Cotton	0.05	Copper	18,35	350	Z	11.6	0.86
Co-SS	20/1	Cotton	0.05	S. steel	35,9	350	Z	12.6	1.33

Table 2. Fabric specifications.

Fabric Code	Weave type	Number of warp yarns (per cm)	Number of weft yarns (per cm)	Fabric weight (g/m^2)	Thickness (mm)
Co-Co-P	Plain	24	25	255,63	1,75
Co-Cu-P	Plain	23	31	266,89	1,69
Co-SS-P	Plain	23	32	254,97	1,68
Co-Co-T	3/1 Twill	24	29	298,68	1,97
Co-Cu-T	3/1 Twill	23	31	270,20	1,84
Co-SS-T	3/1 Twill	23	30	246,36	1,81

$$\text{Formability} = \text{Bending rigidty}\, x \frac{\text{Extension}\,(20) - \text{Extension}\,(5)}{14} . 7 \qquad (2)$$

3. Results and Discussion

Fabric samples were evaluated principally in terms of bending rigidity, formability and drapeability.

The bending length of the fabric samples in warp and weft directions are given in Table 3. Bending length was used for calculating the bending rigidity of the fabric samples, which is demonstrated in Figure 2.

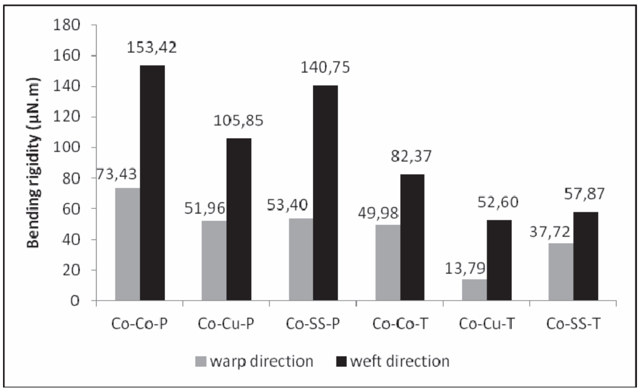


Figure 2. Bending rigidity of the fabric samples.

The results indicated that both weft yarn and weave type have significant impact on bending rigidity of the fabric samples in weft direction. According to the statistical analysis results, it was found that twill weave fabric samples have significantly lower bending rigidity when compared to plain weave fabric samples in both warp and weft directions. This was an expected result, since the yarns have more free space in twill weave structure, which results in lower bending rigidity [44]. Besides, bending rigidity values of the samples in warp and weft directions followed the same pattern in both plain and twill weave types. While the highest values were observed in fabrics produced without metal wire, the lowest values belonged to the samples including copper-covered hybrid yarns. Although the difference was not statistically significant for plain weave fabric samples; it was found to be significant for twill weave fabric samples. The highest bending rigidity values obtained in the fabric samples without metal wire can be explained due to the restricted yarn displacement caused by high friction. Since the metal wires have much more smoother surfaces than the cotton spun yarns, metal-covered hybrid yarns possess lower interfacial friction resulting in lower yarn bending rigidity and hence lower fabric bending rigidity [45]. Moreover, the investigation of the load-deformation behaviour of the fibrous assemblies concluded that the bending moment of yarn is equal to the sum of the bending moment and frictional force of constituent fibres in bending deformation [46]. In the same manner, higher frictional force of constituent yarns in fabric deformation during bending can be stated as the reason of higher bending rigidity. Measured bending rigidity values of the weft yarns used in producing the fabric samples also supported this result; since the bending rigidity of plied cotton yarn was found to be significantly higher than that of metal-covered hybrid yarns. Having higher bending rigidity, the fabric samples produced without metal wire seems to be more manageable during sewing resulting in flat seam [47]; and also, the higher bending rigidity of these fabric samples may result in better shape retention [27]. On the other hand, the fabric samples including metal-covered hybrid yarns have lower bending rigidity values, which require them to be handled more carefully during cutting and sewing processes [48]. It can be stated that when a whole garment is produced from the fabrics including metal-covered hybrid yarns, this may lead inappropriate fit and appearance of the garment during body movements, since lower bending rigidity may result in relatively less shape retention ability, and this situation may appear more frequently in twill weave fabrics. Thus, the fabrics including metal-covered hybrid yarns are more suitable for use in certain parts of the garment, such as front panels and pockets as interlining. Nevertheless, the body movements particularly at body parts such as knees and elbows may cause multidimensional deformation, which cannot be predicted using bending rigidity values in only warp and weft directions. Resistance of the fabric samples to bending in multiple directions should be evaluated by using circular bending procedure in order to find out the behaviour and fitting characteristics of the fabrics in the mentioned body parts. Circular bending rigidity values of the fabric samples are demonstrated in Figure 3. The results imply that the circular bending rigidity of the fabrics increase with the insertion of metal wire into the fabric for both weave types; therefore, it can be stated that the fabrics including metal-covered hybrid yarns have higher resistance to bending in multiple directions. The fabric samples produced by using metal-covered hybrid yarns demonstrated statistically significant higher circular bending rigidity values than that of the fabric samples produced without metal wire. With regard to weave type, circular bending rigidity of the twill weave fabric samples found to be also lower when compared to plain weave fabric samples; however, the difference was only found to be statistically significant for the plain weave fabric sample without metal wire and the twill weave fabric sample without metal wire.

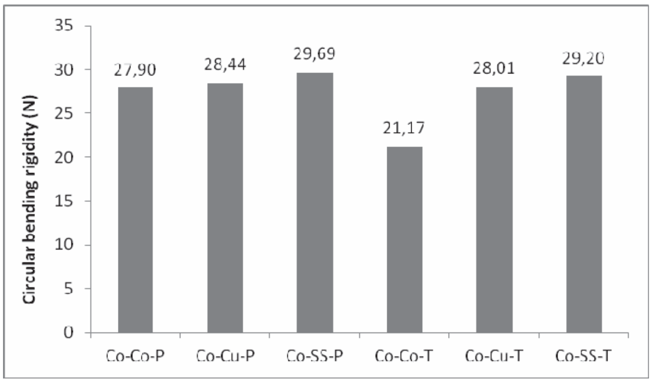


Figure 3. Circular bending rigidity of the fabric samples.

Table 3. Bending length values measured on FAST-2 bending meter.

Sample code	Co-Co-P	Co-Cu-P	Co-SS-P	Co-Co-T	Co-Cu-T	Co-SS-T
Bending length in warp direction (mm)	30,83	27,08	27,75	25,75	17,33	25,00
Bending length in weft direction (mm)	39,42	34,33	38,33	30,42	27,08	28,83

The formability of the fabric samples in warp and weft directions were calculated by using bending rigidity values in Figure 1 and the extensibility values at low loads in both directions given in Table 4. The calculated results were demonstrated in Figure 4.

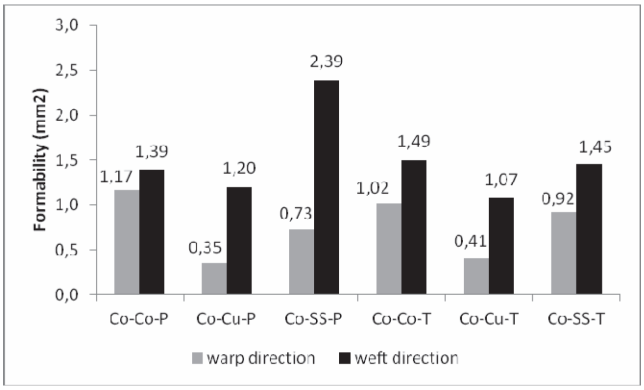


Figure 4. Formability of the fabric samples.

The results showed that the lowest extensibility values at low loads in weft direction were obtained from the samples produced without metal wire, followed by the samples produced by using copper-covered and steel-covered weft yarns in that order, irrespective of the weave type. This result may be related with the elongation of the components of the yarn samples with the values of 7.34%, 18.35%, and 35.97% for cotton yarn, copper wire and steel wire respectively. The extensibility of the fabric samples with metal-covered hybrid yarns was found generally to be higher in warp direction. This can be due to the fact that the smoother surfaces of metal-covered hybrid yarns enable easier slippage of yarns, particularly in the intersecting points of warp and weft yarns, when a force is applied. The twill weave fabrics exhibited greater extension due to looser structure when compared to plain weave fabrics. The looser structure allows yarns and fibres to adjust and realign when deformation forces are applied, which results in higher extensibility [47, 49].

Although the extensibility values of the fabric samples were influenced by type of weft yarn and weave significantly, it was observed that formability of the fabric samples in both warp and weft directions did not change significantly with regard to the mentioned parameters. This means that, the behaviour of the fabric samples is expected to be similar especially during sewing process. In other words, all samples are expected to accommodate the small compression placed on the fabric by the sewing thread similarly; and therefore the tendency of creating seam pucker will be alike [48]. However, in tailoring process, i.e. in the process of converting 2D fabric into 3D form, extensibility and compression play significant roles. When the fabric pieces are sewn together, a slight tension is given on the piece at the top, and in-line compression is given on the piece at the bottom. Thus, tailoring becomes easier with extensible fabrics; but, high extensibility causes unwanted fabric distortion during cutting and sewing [50]. Although the fabrics are expected to behave in the same manner in terms of formability, the fabrics with metal-covered hybrid yarns should be handled carefully in cutting and sewing processes because of their higher extensibility. This is more crucial for the twill weave fabrics.

Drape coefficients of the fabric samples are demonstrated in Figure 5. Drape coefficients calculated for twill weave fabrics were found to be significantly lower when compared to plain weave fabrics. As explained in bending rigidity results, the yarns can move more freely in twill weave structures, which results in lower drape coefficient [44]. Due to the lower drape coefficient, twill weave fabrics can mould into the shape of the human body easier and results in better fit.

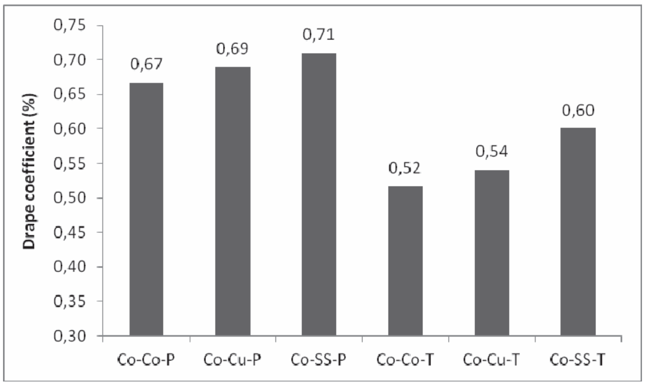


Figure 5. Drape coefficients of the fabric samples.

With regard to weft yarn type, it was observed that drape coefficient of the fabrics produced without metal wire was the lowest, followed by the fabric samples including copper-covered hybrid yarns and steel-covered hybrid yarns respectively for both plain and twill weave types. However, this increase was statistically insignificant, which is expected to lead similar behaviour of the fabric samples in terms of fit. Drape coefficients of the fabrics samples were found to be inconsistent with the bending rigidity values in warp and weft directions, whereas they are consistent with the bending rigidity values in multiple directions, since a fabric is subjected to bending deformation generally in multiple directions, when it is allowed to drape with its own weight. The shapes of the draped fabric samples are demonstrated in Figure 6. Accordingly, the fabric samples without metal wire folded more due to their lower resistance to bending in multiple directions, and this caused a reduction in the projection area of the draped samples. Therefore, they may be adapted to the human body shape smoother.

Table 4. Extensibility values measured on FAST-3 extension meter.

Sample no		**Co-Co-P**	**Co-Cu-P**	**Co-SS-P**	**Co-Co-T**	**Co-Cu-T**	**Co-SS-T**
Extension (5) (%)	Warp	0,07	0,10	0,23	0,13	0,33	0,37
	Weft	0,10	0,17	0,20	0,20	0,23	1,43
Extension (20) (%)	Warp	0,30	0,20	0,43	0,32	0,77	0,93
	Weft	0,23	0,33	0,53	0,43	0,53	1,67


Co-Co-P Co-Cu-P Co-SS-P

Figure 6. Shape of draped fabric samples.

Correlation analysis showed that bending rigidity, drape coefficient and formability of the fabric samples were positively and significantly related. Bending rigidity obtained from the measurements in weft direction was highly and positively correlated with drape coefficient of the fabric samples with the coefficient of 0.78 (significant at 95% confidence interval), which is higher than the significant correlation coefficient of 0.61 (at 95% confidence interval) between bending rigidity and formability, as well as drape coefficient and formability (0.52, at 90% confidence interval). This result is in parallel to the previous findings [51]. Moreover, a high significant correlation was obtained between drape coefficient and circular bending rigidity values (0.76, at 90% confidence interval).

4. Conclusion

This study investigated the bending rigidity, formability and drapeability of the woven fabrics with different weave structures produced from hybrid yarns including metal wire regarding tailorability and fit of the garment.

The statistical analysis confirmed that the relationships between drape coefficient, formability and bending rigidity are significant. Moreover, the analysis showed that weave type had significant influence on bending rigidity, formability and drape coefficient; while weft yarn type influenced only the bending rigidity of the fabric samples.

The results revealed that the fabric samples are expected to behave in the same manner during cutting and sewing processes; however, the fabric samples including metal-covered hybrid yarns; especially the twill weave fabrics, should be handled carefully due to their higher extensibility, as well as their lower bending rigidity in the warp and weft directions.

According to the drape coefficient results, the fitting of the garment in static position is expected to be similar regardless of the weft yarn type, even twill weave fabrics can mould into the shape of the human body easier and results in better fit. On the other hand, lower bending rigidity of the fabric samples including metal-covered hybrid yarns in warp and weft directions may result in relatively less shape retention ability, which is much more crucial for twill weave types. This point should be considered in garment parts that are subjected to deformation in these two directions; while circular bending rigidity values should be taken into account for the garment parts being exposed to deformation in more than two directions.

Thus, the decision about the usage of the fabrics in concern on different parts of the garment is better to be determined considering the relevant bending rigidity values.

The present study contributed to the understanding of the behaviour of the fabrics including metal-covered hybrid yarns in different weave structure in terms of tailorability and fit, which has never been considered before. The fabrics including metal-covered hybrid yarns are suggested to be used in some parts of the garment as a separate layer like interlining. Therefore, the appearance and behaviour of this type of fabrics when used in a layered structure should be evaluated as a future work.

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