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THE DEVELOPMENT AND APPLICATION OF A FABRIC OBJECTIVE MEASUREMENT DATA SYSTEM IN THE SOUTH AFRICAN APPAREL INDUSTRY: HYGRAL EXPANSION AND FORMABILITY

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ABSTRACT

A programme has been initiated with the objective to develop an advanced Fabric Objective Measurement (FOM) based technology, knowledge and data system which is relevant to, and can be implemented in, the South African apparel industry to benchmark and improve the quality of locally produced woven apparel fabrics and garments. To this end, various FOM and other quality related parameters have been measured and analysed for a wide range of commercial worsted type fabrics used in the South African apparel manufacturing industry. This paper deals with one aspect of this data system, namely fabric hygral expansion and formability, two key properties when it comes to the making up (tailorability) of fabrics. Further papers will deal with the other lesser important properties, and ultimately, with the system in its totality.

Some 394 commercial worsted woven type fabrics, of different structure (plain, twill, venetian, gabardine, barathea, hopsack and herringbone) and blend (mainly wool and wool blends), the majority varying in weight between 150 and 300 g/m2 have been sourced from fabric and garment manufacturers and tested on the Fabric Assurance by Simple Testing (FAST) FOM system. The effect of fabric weight, thickness, structure and composition on hygral expansion and formability has been investigated, using ANOVA, the results being presented in tabular and graphical form. It was found that the hygral expansion of the wool fabrics was, on average, higher than that of the wool blend fabrics, while the heavier and thicker fabrics had higher (better) formability in both warp and weft directions. These factors need to be taken into consideration in preparing the envisaged FOM based system.

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INTRODUCTION

The South African apparel industry is facing increasing competition within the global market, especially from the Asian countries, where quality and cost, or more specifically value for money, are often the main order qualifier, apart from other factors, such as quick response, on time delivery, fashion, etc. This is creating a huge question mark over the competitiveness and sustainability of the local labour intensive apparel manufacturing sector, with serious economic and social implications, particularly in terms of job losses. There are many reasons for the lack of competitiveness, including deficiencies in terms of appropriate knowledge, technological know-how and skills and technology systems and capacity. For South Africa (SA) to be globally competitive, it needs to produce, on time and on brief, fabrics and garments, which are of excellent quality, fashionable and represent ‘value for money’, notably in wool and wool blends for the higher value “niche” end of the local and international markets. To achieve this, the highly advanced and integrated Fabric Objective Measurement (FOM) systems, such as Fabric Assurance by Simple Testing (FAST) and Kawabata, widely used in competing countries to improve and ensure the quality of the fabrics and garments, could play a significant role and should be implemented in SA. To produce top quality fashionable garments, particularly from woven worsted fabrics, requires effective utilization of an FOM system, this already being widely used globally to improve and ensure fabric and garment quality.

The reason for the lack of the adoption of FOM systems in SA was investigated by means of a survey of local apparel fabric and clothing manufacturers and retailers (Das, 2011; Das and Hunter, 2015). It was found that only one FAST system was in use in SA, with most apparel fabric and garment manufacturers and retailers apparently carrying little knowledge of FOM systems and their potential benefits. This made it clear that a concerted effort was required to promote and implement FOM in SA, this being considered essential in improving the global competitiveness of the local apparel manufacturing industry dealing with worsted type of fabrics.

Various international studies (Kawabata, 1982; Mahar et al, 1983; Postle et al, 1983; Kawabata et al, 1984, 1986; Ly and De Boos, 1990) publications and conferences have demonstrated the need for upgrading from the mere traditional subjective assessment of fabric quality and tailorability to a more technologically advanced objective measurement system, such as FOM, which is far more accurate and reliable. Furthermore, it has been shown that the adoption of FOM leads to an increase in the added value of products, both in the textile and clothing industries, also facilitating dealing with the many new types of fabrics being developed and coming on to the market (Mahar et al, 1983; Postle, 1989).

Peirce (1930:377) was one of the first researchers to investigate the relationship between subjectively assessed fabric handle and the objectively measured fabric mechanical properties, and can be called “the father of FOM”. After him, many other researchers, notably Postle (1989:72), Kawabata (1982) and Kawabata et al, (1984, 1986), made major contributions towards the technology of the objective measurement of fabric and garment quality related properties, such as handle, making-up and wear performance. This eventually resulted in the culmination of the KES -F system of FOM, popularly known as the Kawabata system (KES systems, 2016), developed by Prof. Kawabata and his team in Japan (Kawabata et al, 1984; 1986). Nevertheless, the system, though ideal for research laboratories and large and advanced fabric and clothing manufacturers, was considered too sophisticated and expensive for wider use. This lead to the development of the FAST system which was more user friendly and less expensive than the Kawabata system (CSIRO, 1989; De Boos and Tester, 1994; FAST systems, 2016). It was developed to provide the industry with a single, robust and relatively inexpensive system for the objective measurement of fabric properties important in tailoring. As rightly stated by Ly and De Boos (1990:370), “while the measurement of fabric properties with FAST is a relatively simple procedure, the interpretation of the data requires an understanding of how each fabric property influences the tailoring performance”. This task is simplified with the help of a FAST Control Chart. In this chart, the measured properties are plotted (plotting can be done automatically when using a PC and the FAST Data Program) and the points joined to give a “fabric fingerprint”, with control limits, which helps in the interpretation of the data, for example whether the fabric tested is suitable for an intended end-use (Postle, 1983; FAST systems, 2016). Prediction of tailoring performance is based on the suggested maximum and minimum limits for each property, as shown in the FAST control chart. If the fingerprint falls outside the limits, it indicates that more work, for example re-finishing, needs to be done on that particular fabric. The FAST control chart indicates all the fabric properties that are tested, including, relaxation shrinkage, hygral expansion, formability, bending rigidity, extensibility, shear rigidity, thickness and weight. Of these, hygral expansion and formability are key for worsted type fabrics from wool and wool blends, and the most likely to be the source of making-up related problems to the South African apparel industry, and have therefore been selected as the focus of this paper.

Hygral expansion

Hygral expansions, and its important effect on tailorability and wear performance, have been extensively studied since the 1960s (Shaw, 1978; 1986). Hygral expansion can be defined as a reversible fabric dimensional change which occurs when the moisture regain of the fabric is altered at a constant temperature (Baird, 1963; Lindberg, 1965). A reversible change in fabric dimensions, particularly wool and wool-rich blends, occurs when the moisture regain of the fabric changes, this being largely due to the wool fibre undergoing reversible swelling. Increasing the regain of wool, leads to radial swelling of the fibres, which causes the fibres and yarns to straighten out and consequently to a decrease in weave crimp, resulting in an increase in both the length and width of the fabric. These changes are reversible, and, on decreasing the regain to its original level, the fabric returns to its former dimensions. Excessive levels of hygral expression (e.g. 5 to 6%) can cause a number of commonly known problems in the appearance of wool and wool blend garments, including bubbling, seam puckering and delamination of the shell fabric. With the ever-changing trends towards light weight fabrics, hygral expansion has become a more serious problem in tailored garments, generally due to such fabric structures allowing easier movement of the yarns (Cookson et al, 1991:135). As already discussed, fabric-related factors which influence hygral expansion include weave crimp, fabric setting and fabric structure

Formability

Fabric formability, derived from fabric bending and longitudinal compressional properties, or from bending and tensile properties, has been shown to be related to tailoring performance (Lindberg et al, 1960; Mahar et al, 1983). As defined by Lindberg et al, (1960), fabric formability relates to the deformation that the fabric can bear before buckling. It provides a measure of how easily the flat, two dimensional, surface of the fabric, can be transformed into a three-dimensional shape, for example, at the shoulder of a jacket. Fabric formability can be used to predict the limit of overfeed before buckling. The lower the formability, the more likely it is also for seam pucker to occur, because the fabric is unable to accommodate the small compression placed on it by the sewing thread (De Boos and Tester, 1994), puckering and sleeve settings representing common problems experienced with low fabric formability. Factors which can influence formability, include weave structure and fabric density (or tightness).

EXPERIMENTAL

Fabrics

Some 394 worsted type woven fabrics, of varying weight (mostly between 150 g/m^2 and 300 g/m^2), weave and blend, were sourced from various local fabric and garment manufacturers (Table 1). The fabrics mainly consisted of wool and wool blends in twill and plain weaves, which is typical of worsted-type suiting fabrics used for men's and ladies suiting's and related formal wear.

FAST tests

The various fabrics were measured on the FAST system in a standard atmosphere (20±3^{0}C & 60±5% RH) according to the test method as

TABLE 1: DETAILS OF FABRICS

Number of fabrics			
Fabric blend	**Twill weave**	**Plain weave**	**Total**
Wool 100%	109	67	203
Wool blends	25	61	99
Others blends	22	58	92
Total	156	186	394

TABLE 2: AVERAGE AND CO-EFFICIENT OF VARIATION VALUES FOR HYGRAL EXPANSION AND FORMABILITY FOR THE VARIOUS FABRIC GROUPS

Fabric structure and blend (Code)	Weight (g/m²)	Thickness (mm)	HE-1 (%)	HE-2 (%)	F-1 (mm²)	F-2 (mm²)
Plain/100% Wool (Pl/100W)	172	0.43	2.24 (19%)*	2.8 (35%)	0.30 (22%)	1.78 (26%)
Plain/blends (Pl/Bl)	169	0.44	0.73 (42%)	0.64 (30%)	0.27 (12%)	0.30 (19%)
Twill/100%Wool (Tw/100W)	179	0.47	2.9 (24%)	3.9 (16%)	0.28 (32%)	0.47 (43%)
Twill/blends (Tw/Bl)	205	0.52	0.9 (33%)	0.9 (17%)	0.42 (28%)	0.33 (19%)

*Values in the parenthesis indicate the CV%.

discussed in the FAST System Instruction Manual (CSIRO, 1989). The FAST system involves three instruments, namely FAST-1, FAST-2 and FAST-3 and a test method FAST-4, as follows:

- FAST-1 measures the fabric thickness,
- FAST-2 measures the fabric bending length and rigidity,
- FAST-3 measures the fabric extensibility and shear rigidity and
- FAST-4 measures the dimensional stability of the fabric, i.e. hygral expansion and relaxation shrinkage, as described below.

Hygral expansion tests

From each of the fabrics, three square samples (300 mm x 300 mm) were cut out for hygral expansion testing. Each sample was marked at the corners and mid-points to represent a square, measuring 250 mm x 250 mm, thus ensuring a 25 mm margin between the edges of the fabric and the measurement region, enabling three warp and three weft measurements to be made for each sample. Samples were conditioned at 65±5% Relative Humidity (RH) and 20±2^{0}C for 24 hours prior to testing. Fabric samples were relaxed, for an hour in a tray containing water and a wetting agent at 35^{0}C, and the wet lengths measured with the fabric immersed. After removal of excess water, by gently patting with a towel, the fabrics were dried in a convection oven for an hour at 105^{0}C. Measurements of the dried fabric dimensions were made within 30 seconds of removal from the oven. Hygral expansion (HE %) was calculated, for both warp (HE-1 %) and weft (HE -2 %) directions, as follows:

$$HE\ \% = \frac{Wet\ length\ - Dry\ length}{Dry\ length}\quad \text{X } 100$$

Formability (F) is not measured directly, but is derived from other FAST parameters as: Formability = bending length * extensibility (Tester, 1988). More specifically this can be expressed as F = (E20 – E5) x B/14.7 (where F = formability of the fabric; E20 = extensibility of the fabric at 20 gf/cm; E5 = extensibility of the fabric at 5gf/cm; B = bending rigidity of the fabric).

Statistical analysis

Statistical analyses (ANOVA) were carried out on the formability and hygral expansion results, with a view to compare the different fabrics in terms of their hygral expansion and formability, and also to find out if fabric weight, thickness, weave structure (plain and twill) and blend (100% wool and wool blend) had a significant effect on hygral expansion and formability since this is important when preparing a meaningful and useful database from a practical point of view. The results of the tests and statistical analyses are presented in tabular or graphical form, as appropriate, and are discussed below.

RESULTS AND DISCUSSIONS

The average and co-efficient of variation (CV %) values for the relevant FAST properties are given in Table 2 for the various wool and wool blend fabrics groups.

Hygral expansion

The ANOVA analysis on hygral expansion, in the warp direction (HE -1%) showed that fabric weave structure and blend had a statistically significant effect (Table 3), whereas fabric weight and thickness did not. According to Baird (1963; 1989) fabric structure restricts hygral expansion, and according to Shaw (1978; 1986) the weave crimp is the fabric structural feature having the most important influence on hygral expansion, the greater the yarn (i.e. weave) crimp, the greater the hygral expansion. The effect of fabric weave is most likely due to the

TABLE 3: ANOVA ANALYSIS ON HE-1(%) RESULTS

	SS	Degr. Of Freedom	MS	F	p				
Intercept	72.58237	1	72.58237	54.65999	0.0000				
Weight (g/m²)	0.055513	1	0.055513	0.041806	0.8381				
Thickness (mm)	0.038001	1	0.038001	0.028618	0.8658				
Fab. Structure	8.166845	1	8.166845	6.150249	0.0137		**Multiple R**	**Multiple R-sq**	**Adj. R-sq**
Blend	194.4533	1	194.4533	146.438	0.0000				
Error	414.3012	312	1.327888				0.6238	0.3891	0.3813

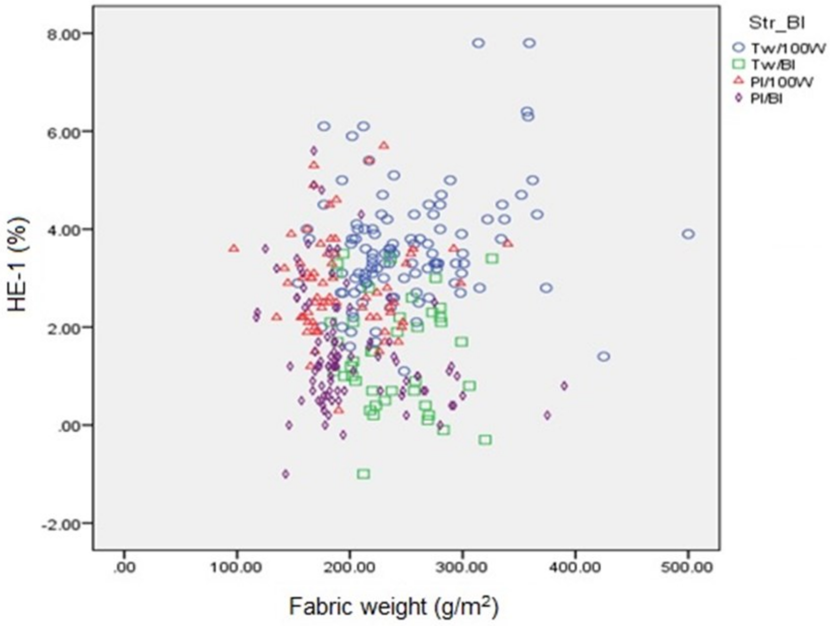

Figure legends (Codes)
Tw/100W: Twill weave, 100% wool
Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 1(a): HE-1% VS FABRIC WEIGHT, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

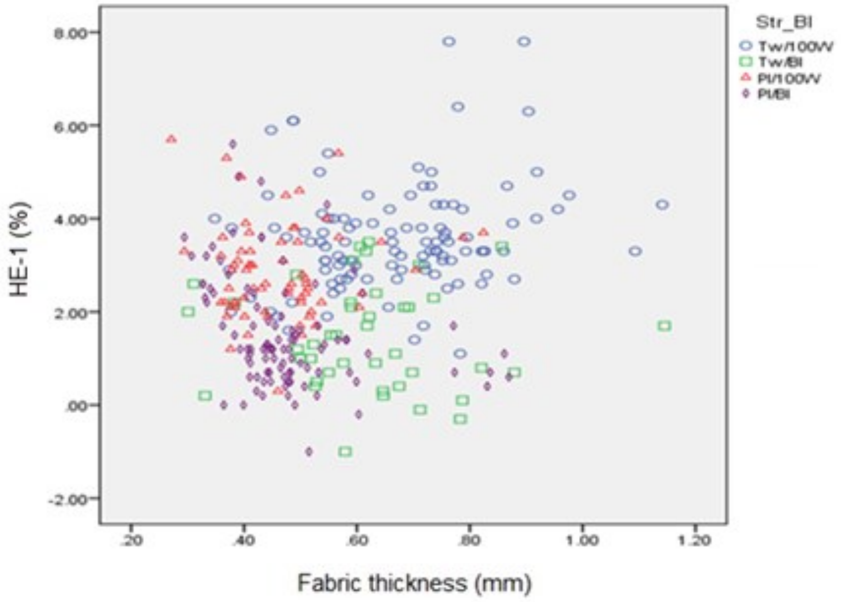

Figure legends (Codes)
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Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 1(b): HE-1% VS FABRIC THICKNESS, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

TABLE 4: ANOVA ANALYSIS ON HE-2(%) RESULTS

	SS	Degr. Of Freedom	MS	F	p				
Intercept	196.0854	1	196.0854	100.6905	0.0000				
Weight (g/m^2)	51.5138	1	51.5138	26.45252	0.0000				
Thickness (mm)	13.54386	1	13.54386	6.954822	0.0088				
Fab. Structure	5.172992	1	5.172992	2.65635	0.1041		**Multiple R**	**Multiple R-sq**	**Adj. R-sq**
Blend	377.4092	1	377.4092	193.801	0.0000				
Error	607.5907	312	1.947406				0.6713	0.4507	0.4436

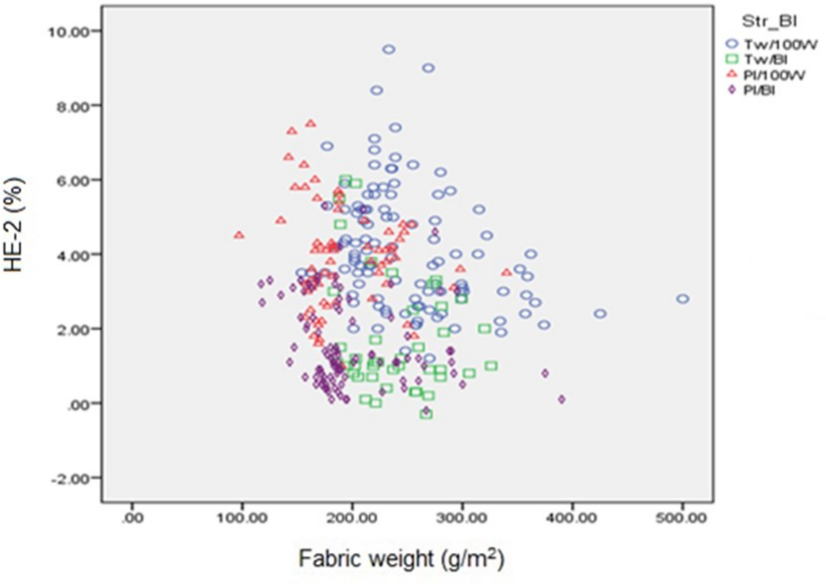

Figure legends (Codes)
Tw/100W: Twill weave, 100% wool
Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 1 (c): HE-2% VS FABRIC WEIGHT, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

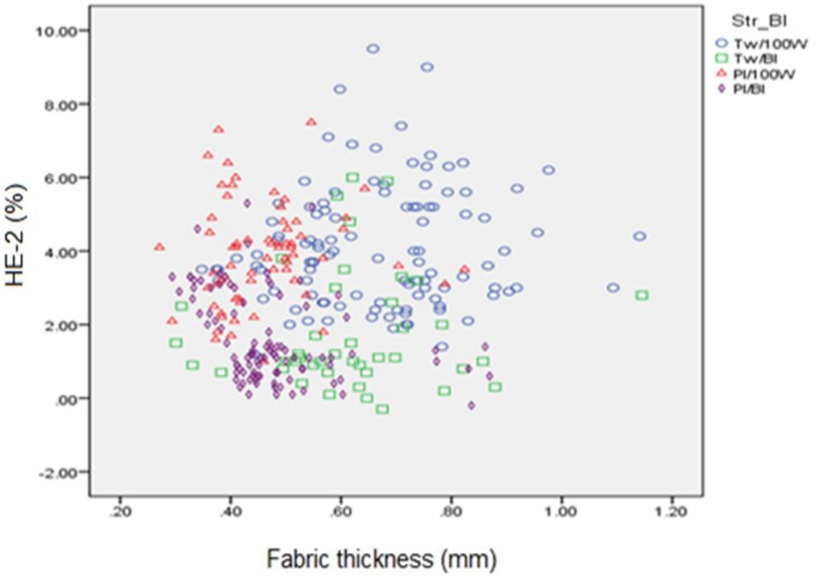

Figure legends (Codes)
Tw/100W: Twill weave, 100% wool
Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 1 (d): HE-2% VS FABRIC THICKNESS, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

weave crimp generally being higher in twill than in plain weave fabrics, together with the twill weave producing less restriction on the yarn movement than the plain weave. The greater hygral expansion of the pure wool fabrics is easily explained in terms of the greater swelling properties of wool vis-à-vis that of the synthetic fibre component (mainly polyester) present in the wool blends. As already explained, such fibre swelling results in a decrease in weave crimp, and therefore greater hygral expansion. To illustrate the differences in HE-1% due to blend and weave structure, HE-1% has been plotted against fabric weight in Figure 1(a) and against fabric thickness in Figure 1(b), different symbols and colours being used to represent the different fabric groups. What is clear from Figures 1 (a) and 1 (b), is that the individual hygral expansion values of the different weave structures and blends overlap considerably, and are only an average different. Similar statistical (ANOVA) analyses was carried out on the hygral expansion in the weft direction (HE-2%) as was done on HE-1%, the results being given in Table 4. From Table 4 it is apparent that fabric weight, thickness and blend all had a statistically significant effect on HE-2%, whereas fabric weave structure did not. This differs somewhat from that observed for HE-1%, where only fabric weave structure and blend had a statistically significant effect. Once again, the pure wool fabrics, both plain and twill weaves, had a higher hygral expansion than the wool blend fabrics, the explanation being as for HE-1%. Although statistically not significant, the tendency was once again, as in the case of HE-1%, for the twill weave fabrics to have a higher hygral expansion than the plain weave fabrics (see Table 2). To illustrate some of the above effects, HE-2% has been plotted against fabric weight and thickness in Figures 1 (c) and (d), respectively.

On average, the heavier and thicker fabrics tended to have higher HE-2 % values than the lighter and thinner fabrics, which is different to what was found for HE-1% and contrary to the work of Cookson et al, (1991). This could be due to associated differences in the weave crimp and yarn linear density in the weft direction. Neverthless, it is apparent from Figure 1 (b), that, as in the case of HE-1, there is a considerable overlap in the individual fabric results for the different blends and structure. To compare the HE-2 values of the different fabric structures and blends, HE-2 % has been plotted against fabric weight and thickness in Figures 1 (c) and 1 (d), respectively.

From the above figures and tables, particularly Table 2, it is apparent that, in both warp and weft directions, the hygral expansion of the wool fabrics was, on average, higher than that of the wool blend fabrics. This is not difficult to understand, since the blends mainly contained polyester which has a very low regain and therefore swelling, resulting in a lower hygral expansion. Therefore, when preparing a FAST database, and average or benchmark values, for use by local fabric and garment manufacturing, appropriate allowance must be made for the effects observed and discussed above.

Formability

The ANOVA tests on formability showed (Tables 5 and 6) that only fabric thickness had a statistically significant effect on the formability in the warp direction (F-1 mm^2) whereas fabric weight, thickness and blend all had a statistically significant effect on the formability in the weft direction (F-2 mm^2).

The twill blend fabrics had, on average, the highest formability in the warp direction (F-1 mm^2), while the plain 100% wool fabrics had the highest formability, by far, in the weft direction (F -2 mm^2). To illustrate the differences in weft formability (F-1 mm^2) due to fabric structure and blend, F-1 has been plotted against fabric weight and thickness in Figures 2 (a) and 2 (b) respectively, F-1 tending to increase with an increase in fabric weight and thickness.

A similar analysis to that carried out on F-1, was carried out on F-2, the results of the analysis being given in Table 6.

According to the ANOVA results given in Table 6, the fabric weight, thickness and blend all had a statistically significant effect on the formability in the weft direction (F-2 mm^2), only fabric weave structure not having a statistically significant effect. The plain weave all wool fabrics (Pl/100W) had, on average, the highest formability, followed by the twill weave all wool fabrics (Tw/100W), indicating that, in the weft direction at least, the all wool fabrics had superior formability compared to the wool blend fabrics. To illustrate differences in formability in the weft direction (F-2) associated with the different fabric weave structure and blend, F-2 has been plotted against fabric weight and thickness in Figures 2 (c) and (d), respectively.

TABLE 5: ANOVA ANALYSIS ON F-1 (mm^2) RESULTS

	SS	Degr. Of Freedom	MS	F	p				
Intercept	7.14227	1	7.14227	42.40991	0.0000				
Weight (g/m2)	0.645838	1	0.645838	3.834905	0.0511				
Thickness (mm)	13.3854	1	13.3854	79.48082	0.0000				
Fab. Structure	0.388953	1	0.388953	2.309556	0.1296		Multiple R	Multiple R-sq	Adj. R-sq
Blend	0.097725	1	0.097725	0.580279	0.4468				
Error	52.54404	312	0.16841				0.628075	0.394478	0.386715

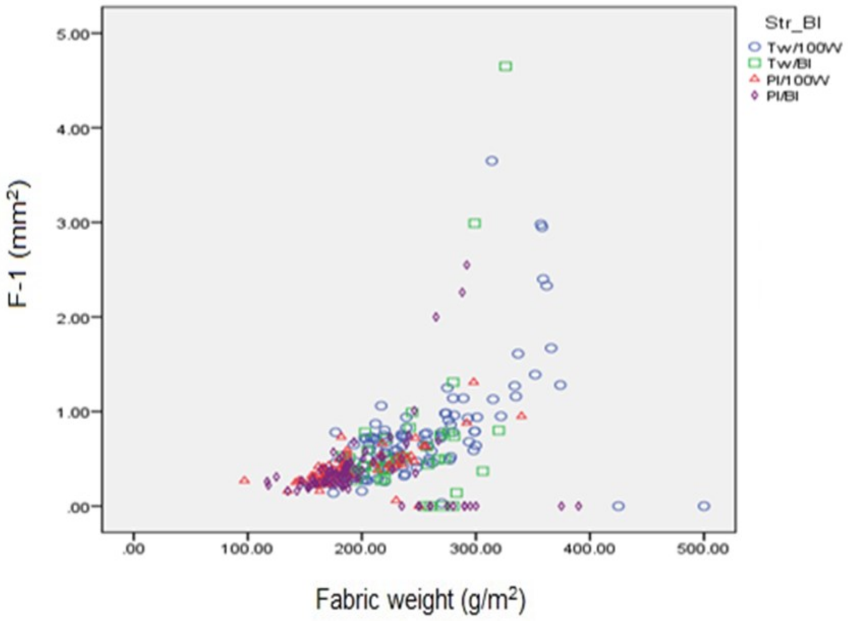

Figure legends (Codes)
Tw/100W: Twill weave, 100% wool
Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 2 (a): F-1 VS FABRIC WEIGHT, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

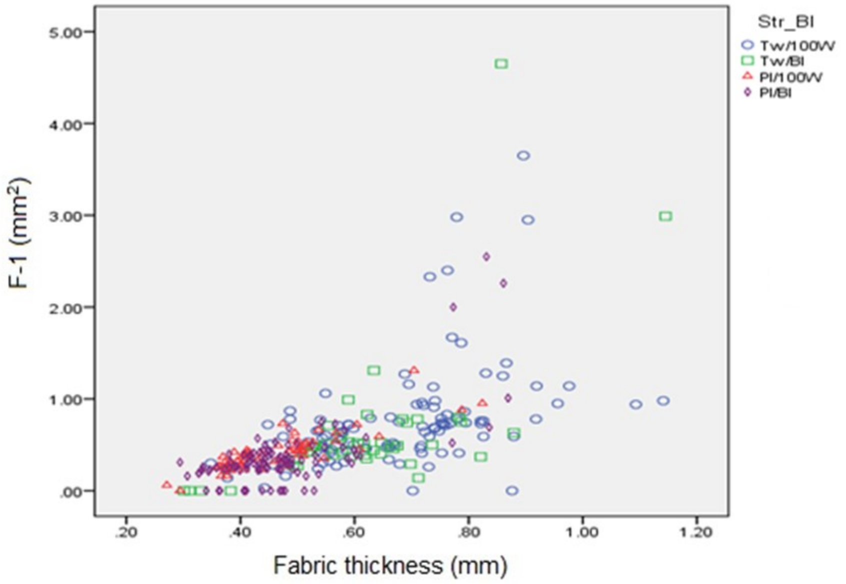

Figure legends (Codes)
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Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 2 (b): F-1 VS FABRIC THICKNESS, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

TABLE 6: ANOVA ANALYSIS ON F-1 (mm^2) RESULTS

	SS	Degr. Of Freedom	MS	F	p				
Intercept	0.458069	1	0.458069	5.524282	0.0194				
Weight (g/m^2)	6.011595	1	6.011595	72.49949	0.0000				
Thickness (mm)	14.122	1	14.122	170.3106	0.0000				
Fab. Structure	0.009566	1	0.009566	0.115366	0.7343		Multiple R	Multiple R-sq	Adj. R-sq
Blend	4.173122	1	4.173122	50.32761	0.0000				
Error	25.87077	312	0.082919				0.7034	0.4948	0.4883

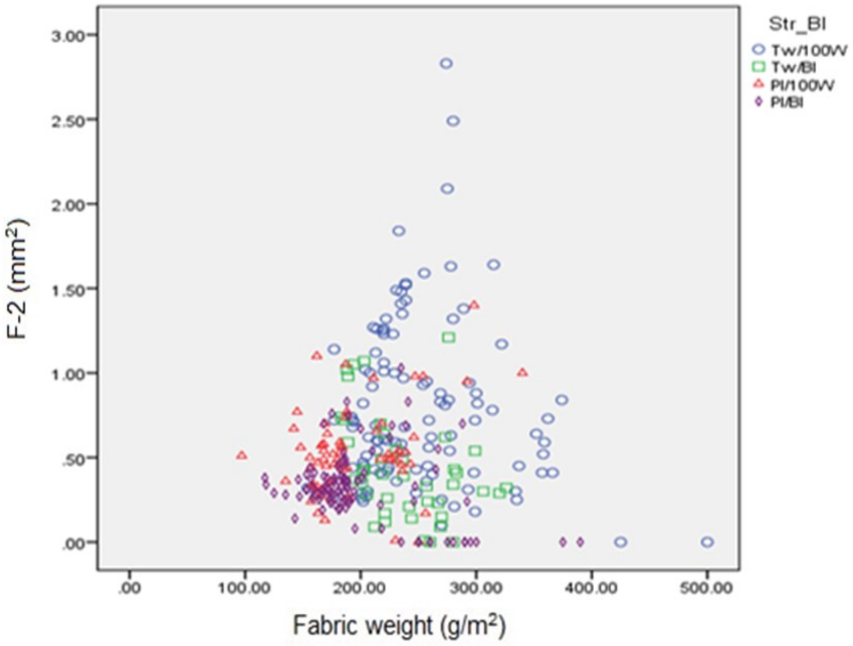

Figure legends (Codes)
Tw/100W: Twill weave, 100% wool
Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 2 (c): F-2 VS FABRIC WEIGHT, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

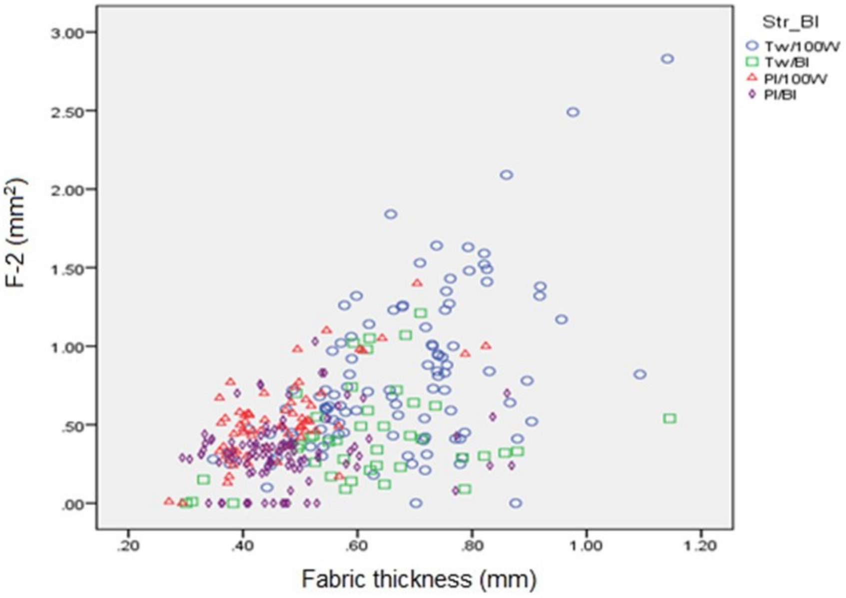

Figure legends (Codes)
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Tw/Bl: Twill weave, wool blends,
Pl/100W: Plain weave, 100% wool
Pl/Bl: Plain weave, wool blends

FIGURE 2 (d): F-2 VS FABRIC THICKNESS, FOR THE DIFFERENT FABRIC WEAVE STRUCTURES AND BLENDS

Figures 2 (a) to (d) illustrate that fabric formability in both the warp and weft directions tend to increase with an increase in fabric thickness and weight, with the formability of the wool fabrics tending to be higher than that of the wool blend fabrics. This shows that the heavier and thicker wool fabrics should be easier to form into three-dimensional shapes during making-up, and therefore perform better than lighter and thinner wool blend fabrics. This also needs to be taken into consideration when preparing the corresponding FAST database and benchmark values. It is once again important to note that the individual fabric results overlap greatly.

CONCLUSION

Many countries have implemented fabric objective measurement (FOM) to the benefit of their apparel fabric and clothing manufacturing sectors, particularly those involved in the high quality worsted woven suiting's end of the market. A survey has shown that South Africa seriously lags behind its global competition in this respect, which adversely affects its global competitiveness. To address this, a comprehensive programme has been initiated, with the ultimate objective of developing an FOM data based knowledge system and technology which can be applied in the South African apparel fabric and garment manufacturing industries for benchmarking and quality control and improvement purposes, thereby assisting them in their quest to become more globally competitive.

To achieve the above objective, almost 400 worsted type commercial fabrics, mainly in wool and wool blends, were sourced from local apparel fabric and clothing manufacturers and tested on the FAST FOM system. This paper, the first in a series, deals with two of the most important FAST derived fabric properties, namely hygral expansion and formability, both of which have a major effect on fabric making-up (tailorability) and garment wear performance. The focus of the paper has been on determining, initially by ANOVA, the influence of fabric weight, weave structure (plain and twill weaves), thickness and fibre composition (pure wool and wool blend) on fabric hygral expansion and formability, since these are important aspects which need to be clarified prior to the development of the intended FOM knowledge based system and benchmarks which are meaningful and useful in practice. Briefly stated, the ANOVA showed that the hygral expansion of the 100% wool fabrics was, on average, higher than that of the wool blend fabrics, which is easily explained in terms of the greater swelling of wool fibres compared to synthetic fibres, such as polyester, when regain is increased. Furthermore, the hygral expansion of the twill weave fabrics was on average, higher than that of the plain weave fabrics, probably due to associated differences in yarn weave crimp and freedom of movement within the respective weave structures. The formability of the plain weave all wool fabrics was highest on average, followed by the twill weave 100% wool fabrics, and then the twill weave wool blend fabrics. Nevertheless, it is important to note that, in all cases, the results of the individual fabrics overlapped greatly.

It is intended that further publications, based on this research work, will cover the various other FAST properties and, eventually, the knowledge based FAST FOM system.

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