(REFEREED RESEARCH)

# ASSESSMENT OF SPINNABILITY OF COTTON FIBRES BY COMPRESSION METHOD

# SIKIŞTIRMA METODU İLE PAMUK LİFLERİNİN EĞRİLEBİLİRLİĞİNİN TESPİTİ

*Mehmet Emin YÜKSEKKAYA*
*Uşak University, Textile Engineering Department*
*e-mail: mehmetemin.yuksekkaya@usak.edu.tr*

**ABSTRACT**

In this study, a new compression tester was evaluated in order to determine the spinnability of different cotton fibres. For this purposes, various colours of dyed cotton fibres were chosen for spinning test in order to determine the relationship between the frictional properties and the spinnabilty of cotton fibres. The surface characteristics of cotton fibres were modified during the dyeing applications by adapting a different processing time. The Quickspin® system was employed to provide a rapid assessment of the likely processing problems associated with different cotton fibres. It was found that a higher load was necessary in order to compress the dark coloured cotton samples due to the changes occurred on the surface properties of fibres. It was observed that it was easier to spin the cotton fibres having the linear compression curves. Additionally, it was seen from the analysis of the data that the fibres having a higher compression force reducing the spinnablity of cotton fibres.

**Key Words:** Compression curve, Spinnability, Drafting force, Stick-slip, Surface properties.

**ÖZET**

Bu çalışmada yeni bir sıkıştırma test cihazının farklı pamuk liflerinin eğrilebilirliğinin tespitinde kullanılabilirliği araştırılmıştır. Bu amaç için farklı renklere boyanmış pamuk lifleri seçilerek elyafın sürtünme özellikleri ile eğrilebilmesi arasındaki bağlantı incelenmiş aralarındaki ilişki belirlenmeye çalışılmıştır. Pamuk liflerinin yüzey özellikleri boyama sürelerinin farklı olması sebebi ile farklılık göstermiştir. Farklı elyafların eğrilebilme özelliğinin belirlenmesinde karşılaşılan problemlerin hızlı bir şekilde tespit edilebilmesi için Quickspin® "hızlı eğirme" sistemi kullanılmıştır. Elyaf yüzeyinde meydana gelen değişiklikler sebebi ile koyu renkte boyanmış olan pamuk örneklerin aynı oranda sıkıştırılabilmeleri için daha fazla sıkıştırma kuvvetine ihtiyaç olduğu tespit edilmiştir. Çalışmalar neticesinde doğrusal bir sıkıştırma eğrisine sahip olan pamuk liflerin daha kolay eğrilebildiği gözlemlenmiştir. Ayriyeten verilerin analizinden görülmüştür ki sıkıştırma işlemi esnasında yüksek sıkıştırma kuvvetine ihtiyaç duyulan elyafın eğrilebilme özelliğinin azalmakta olduğu izlenmiştir.

**Anahtar Kelimeler:** Sıkıştırma eğrisi, Eğrilebilirlik, Çekme kuvveti, Kayma-yapışma, Yüzey özellikleri.

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## 1. INTRODUCTION

Traditionally, most of the mechanical problems in elementary physics and mechanics courses were solved by ignoring the effect of friction due to the fact that the inclusion of frictional forces made the analysis too complicated. Friction does have an important role in textile applications. During the spinning process, for example, it is the only force holding the fibres together if no twist is present (1, 2).

During the last three decades, the production speeds of textile machineries have been improved. To make the best use of this improvement, a precise measurement of the properties of fibres is a must. The frictional characteristic of fibres is a very important property at all stages in the conversion of fibres into an end product. For example, in the spinning process, one meter of the fibre mat is expanded approximately into 2000 meters of the corresponding yarn. During this enormously fast process, fibres interact with each other as well as with the machine's parts. The study of friction has attracted the attention of many workers, particularly after the extensive work done on the mechanical properties of solid materials. The main interest of many workers led to the investigation of the actual physical characteristics of the friction. In order to have a better control of the fibres in the drafting field, numerous types of drafting mechanisms have been developed over the years (3, 4). De Luca (5) reported that in roving, drafting force and frictional properties were more important than torsion and bending rigidities. Today, most of the characteristics of the textile fibres can be assessed by using an appropriate testing instrument; however, the frictional characteristics of fibres are still a challenging issue.

In general, it is desired to have a low fibre friction during drawing process in order to avoid a high resistance to the drafting forces. However, a certain level of friction is also required for a better cohesion during the spinning process. Therefore, it is important that the frictional coefficients of a fibre should be in an acceptable range.

The general characteristics of textile fibres are their fineness, flexibility, and interesting morphological structures, some of which can be measured by AFIS instrument (17). All of the properties have some effects on the frictional characteristics of fibres. Gralen (6) conducted an inter-fibre friction test and showed that the classical law of friction was not valid for fibrous structures. The frictional force generally decreases with increasing load. Furthermore, the coefficient of friction is not a constant, and there is not a simple expression for its description. Therefore, the evaluation of the friction for textile materials is not an easy task.

Over the past years, different types of instruments have been developed to measure the frictional characteristics of fibres. Some of the methods were used for fundamental research works while others were used for practical investigation related to the processing. Although different types of instruments have been developed for the inter-fibre friction test, all of them are in one of the following categories (7, 8, 9, 10):

- Area-Contact Method,
- Line-Contact Method, and
- Point-Contact Method.

Each of these methods is actually a simulation of the rubbing action. The last two methods usually require a length of fibres that are long enough to permit sliding during the friction test. These methods also require a very large sample size in order to obtain a reliable result. The point-contact and the line-contact methods can be used with synthetic filaments and long staple fibres such as wool and silk. The area-contact method would be a better choice for assessing the frictional characteristics of cotton fibres. This is because, in practice, cotton fibres tend to move in groups rather than individually. The area-contact method also gives more accurate results for the frictional behaviour of staple fibres (10, 11, 12, 13).

During the compression of fibre assemblies, pressure, **P**, is applied to a fibre mass, and this pressure causes a volume change in the fibre assembly. Other physical changes also occur during compression; however, the bending and surface properties of the fibre have the most influence on the compressive characteristics of fibres. The conventional method of conducting compression tests on fibrous masses consists of a “piston-in-cylinder” arrangement. The energy required to compress the fibre masses includes the energy expended in overcoming friction between fibres and cylinder wall, bending energy of fibres, and crimp. The relationships between fibre properties and the bulk compression characteristics of fibres have been studied in many experiments. Most of the studies regarded estimation of the number of contact points among the fibre assemblies. The main difficulty for this estimation is that the density function of orientation is not clearly defined in many studies. (14, 15, 16).

The techniques that are currently available for quantifying the fibre friction are either based on single fibre tests or rely on the preparation of a suitable sample by partly processing the fibres, in which “identically” treated fibres are used in the test. Single fibre tests do not reveal the true characteristics due to the fact that fibres tend to behave as a bundle rather than individually. Therefore, it would be more meaningful to have a technique to assess a mass of fibres rather than for an individual fibre. Yuksekkaya and Oxenham (18, 19) have developed an instrument as shown in Figure 1 in order to assess the frictional properties of fibres based on a compression test. In this study, this instrument has been used to evaluate the spinnabilty of the different cotton fibres. For this purposes, the surface characteristics of cotton fibres were modified by adapting different colours. It is expected that depending on the shade of the colours, the frictional properties of the cotton fibres would be different. The aim of the evaluation of the apparatus is to see if it were possible to detect these changes with the friction tester.

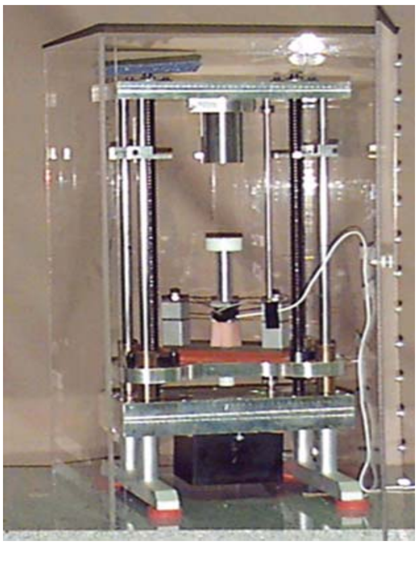

**Figure 1.** Picture of the compression tester

## 2. EXPERIMENTAL

The new instrument takes a “bundle” of fibres and gives the overall frictional characteristic of the fibre tested. The testing system is analogous to squeezing a bundle of fibres. The constant speed of the cross head was set up 1.325 cm/min during the compression and 2.650 cm/min during the decompression. This was giving a constant volume decrease and increase during the test since there is no change on the cylinder diameter. The measured resistance and the compression curve were related to the frictional properties of the fibre surface.

In the experimental part of this work, large samples of cotton fibres were tested to determine whether the instrument was capable of providing useful information about the spinnability of cotton fibres. As known the physical properties of cotton fibres vary a lot. In order to eliminate this variation effect, one type of cotton was selected and the surface of cotton fibres was modified by dyeing them with different colours. Therefore, cotton fibres were dyed by using 12 different colours in two categories, namely, light and dark colours. Raw cotton fibres were also taken for compression tests. The samples were taken from a commercial dye house for spinnability tests. The colours were tried to be chosen from the colour spectrum. It is also important that the dyeing of fibres carried out at a commercial dye house at which the dyeing process cannot be controlled by the author. Since the main objective of this research was to evaluate the compression testing device, it was thought that a standard dyeing recipe would be sufficiently enough for the experimental purposes. During the dyeing, the wax of the raw cotton was removed. Depending on the shade of colours different amount of reactive dye materials have been used. The physical properties of samples were measured by using AFIS and HVI (fibre length, fibre strength, and micronaire values). Although the colour names are given subjectively, the colour measurements were taken by using a commercial colour measurement instrument. The compression curve of each colour was obtained from the compression tester. The maximum compression force and the curvature of the diagram have been compared for different cotton fibres. Then, the Quickspin® machine was used to evaluate the spinnability, start-up breaks, and number of breaks. The Quickspin® system is a laboratory type of spinning box and its working environment is standard textile laboratory condition. To prepare a sliver for the Quickspin® rotor unit, fibres have to be processed three times through the rotoring machine. Although this is nothing but a simulation of an actual drafting process, it is also damaging the fibres. All of these effects have to be considered during the assessment of spinnability test. The cotton samples were used to produce 30 tex single ply yarn with twist multiplier, 3790 (t/m)*sqrt (tex). After spinning, the tenacity of the corresponding yarn was also measured. Table 1 shows the physical properties of cotton fibres, CV%, and Quickspin® test results for the coloured cotton samples. Spinnability index, given by the operator's judgments, is on a three-point scale with one being the hardest to spin, and three being the easiest to spin.

## 3. RESULTS AND DISCUSSION

The spinnability of fibres is also related to the linear density of fibres. As seen in Table 1, the linear density of the dark fibres becomes larger after dyeing. As the linear density of fibres increases, its flexural rigidity also increases. This may be the reflection of the data from the Quickspin® results as difficulty and higher breakage during spinning. As seen in Table 1, the number of breaks for light coloured fibres is less than that of dark coloured fibres. It is well known that chemical treatment can modify the surface of fibres. Therefore, dyeing cotton fibres with different dyes could have changed the frictional properties of fibres. In order to investigate a possible relationship between the number of breaks and maximum compression force, the peak value of compression force was also given in Table 1. As seen in the table, a sample having a low compressive force output most likely reduces the number of breaks during spinning.

After measuring the physical properties of coloured cotton fibres, all samples were subjected to the compression test. Figure 2 through Figure 14 show the compression curves for raw and coloured cotton samples. As seen in Figure 2, the compression load is higher for raw cotton sample. This is related to the sticky wax found on the surface of the cotton samples. During the dyeing processes, the wax on the surface of the cotton fibres was removed by a chemical treatment. Therefore, the observed compression loads on the coloured samples were not as high as that of on the raw cotton samples. It was observed that light coloured cotton fibres exhibited almost a linear shape of compression curve, whereas dark coloured cotton fibres showed more curved one. The stick-slip may be related to the flexural rigidity of fibres as well as change in the fibre length. The change in the fibre length can give significantly different contact points in the fibre assembly, which cause increase or decrease on the amount of compressive force necessary to squeeze the bundle until the specified distance.

The Quickspin® test results, shown in Table 1, are a list of observations made during the Quickspin® process; and are completely based on the operators' subjective judgments. From the experiment, an overall tendency can be seen based on the distinction

**Table 1.** Physical properties of fibres, yarns, and Quickspin® test results for the colour cotton samples

| Colour | | Spinnability | Start-up Breaks | Number of Breaks | Average Load (*cN*) | CV% of Load | Fibre Fineness (*dtex*) | CV% of Fineness | Initial Fibre Length (*mm*) | CV% of Initial Length | Fibre Length in Sliver (*mm*) | CV% of Fibre Length in Sliver | Fibre Tenacity (*cN/tex*) | CV% of Fibre Tenacity | Yarn Tenacity (*cN/tex*) | Stdev of Yarn Tenacity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dark | Bark | 2 | No | 2 | 141.00 | 2.78 | 1.95 | 1.18 | 27.2 | 3.87 | 25.1 | 4.13 | 26.85 | 3.91 | 7.58 | 4.06 |
| | Black | 1 | Yes | 2 | 138.50 | 2.81 | 1.87 | 1.20 | 27.6 | 3.92 | 25.7 | 4.26 | 26.14 | 3.85 | 9.82 | 4.02 |
| | Brick Red | 2 | Yes | 4 | 135.00 | 2.73 | 1.88 | 1.17 | 28.4 | 3.98 | 26.2 | 4.22 | 25.78 | 3.92 | 9.88 | 4.10 |
| | Dark Navy | 1 | Yes | 4 | 183.50 | 2.90 | 1.86 | 1.21 | 26.1 | 3.78 | 25.3 | 4.15 | 26.93 | 3.84 | 10.02 | 4.05 |
| | Evergreen | 1 | No | 3 | 175.50 | 2.85 | 1.91 | 1.25 | 27.3 | 3.82 | 26.2 | 4.20 | 25.80 | 3.90 | 9.73 | 4.12 |
| | Grape | 2 | Yes | 3 | 167.00 | 2.82 | 1.82 | 1.19 | 28.5 | 3.97 | 26.8 | 4.27 | 26.17 | 3.91 | 9.96 | 4.15 |
| Light | Golden Wheat | 3 | Yes | 2 | 64.50 | 2.10 | 1.72 | 1.15 | 30.4 | 3.91 | 29.4 | 4.12 | 28.72 | 3.84 | 10.25 | 4.03 |
| | Kelly Green | 2 | Yes | 1 | 57.50 | 2.25 | 1.63 | 1.16 | 30.8 | 3.96 | 28.9 | 4.29 | 29.15 | 3.81 | 11.24 | 43.98 |
| | Orange | 3 | No | 0 | 62.00 | 2.36 | 1.74 | 1.14 | 29.7 | 3.84 | 28.1 | 4.09 | 28.90 | 3.92 | 10.97 | 4.17 |
| | Rose | 2 | No | 0 | 54.50 | 2.39 | 1.79 | 1.15 | 27.6 | 3.81 | 25.9 | 4.11 | 29.84 | 3.85 | 10.38 | 4.11 |
| | Sage | 2 | No | 1 | 56.00 | 2.23 | 1.68 | 1.15 | 28.1 | 3.99 | 25.7 | 4.28 | 30.05 | 3.82 | 11.37 | 4.19 |
| | Yellow | 3 | Yes | 2 | 63.00 | 2.19 | 1.76 | 1.14 | 27.9 | 3.80 | 26.5 | 4.18 | 29.62 | 3.92 | 10.30 | 4.16 |
| *Control (Raw Cotton)* | | 1 | Yes | 5 | 203.00 | 3.05 | 1.58 | 1.18 | 31.27 | 3.72 | 28.7 | 4.03 | 31.85 | 3.71 | 11.53 | 4.04 |

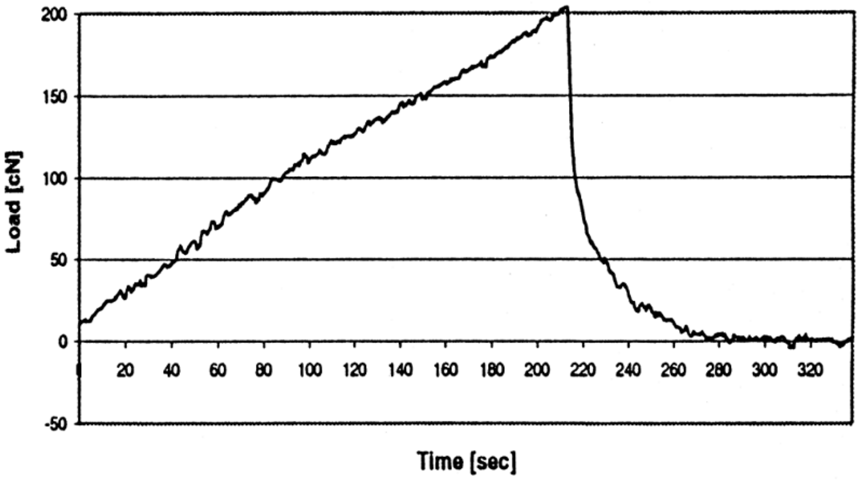


**Figure 2.** Compression curve of raw cotton sample

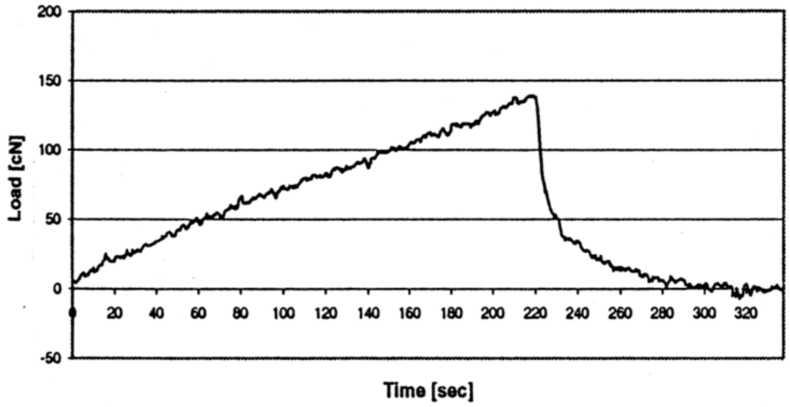


**Figure 3.** Compression curve of Bark colour cotton sample

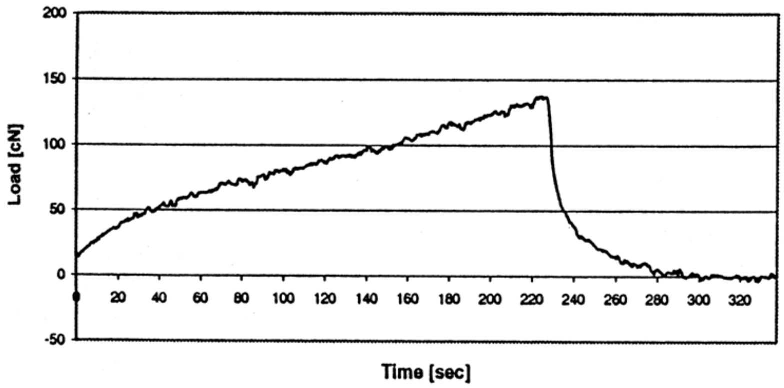


**Figure 4.** Compression curve of Black colour cotton sample

of the colours. If the reader adds up the number of breaks during spinning, the results show that light coloured cotton should run better in the spinning process than dark colours.

Furthermore, the maximum compression force measured from the instrument is also related to the colour of cotton fibres. As seen in Table 1, there is a tendency that the light coloured fibres have a lower compression force than dark coloured fibres. Although, this suggests that (under the same conditions) a lower compression force can give an easy spinning process, this may not be the correct conclusion due to the

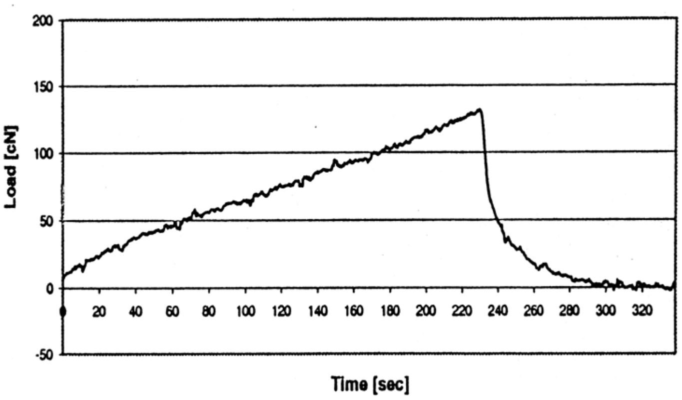


**Figure 5.** Compression curve of Brick Red colour cotton sample

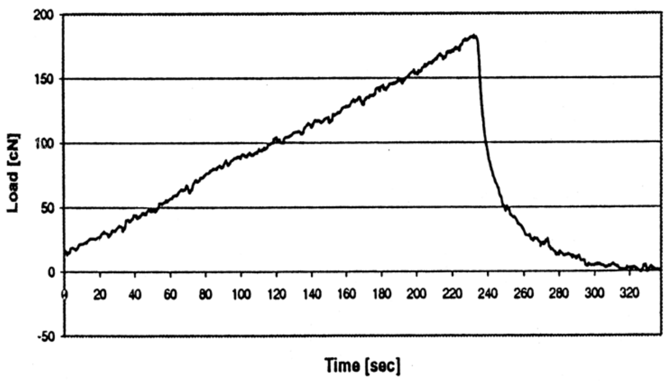


**Figure 6.** Compression curve of Dark Navy colour cotton sample

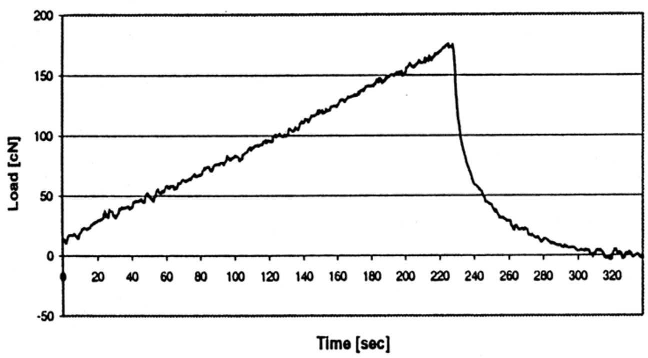


**Figure 7.** Compression curve of Evergreen colour cotton sample

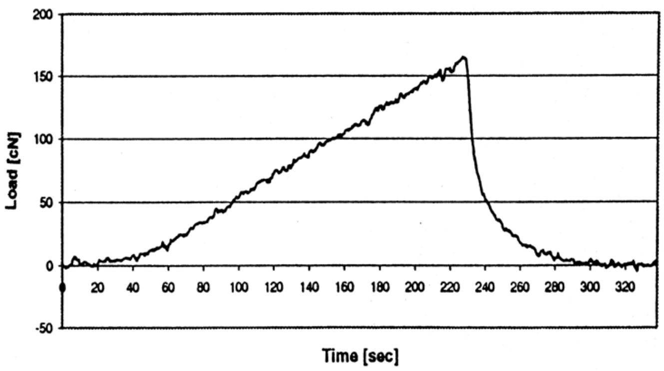


**Figure 8.** Compression curve of Grape colour cotton sample

spinnability of fibres is also related to the length and fineness of fibres. The compression force obtained from the instrument is just the resistance among the fibres and treated as an indicator factor for spinnability of fibres. In tuition, it would be expected that the higher the compression force would give the higher yarn tenacity. However, yarn tenacity was mainly affected by the fibre tenacity. As seen in Table 1, the fibre tenacity for dark colour is lower than that of light colour which results lower yarn tenacity for the tested samples. Additionally, it should be kept in mind that since the yarn breakage is higher for dark colour samples, this is another factor to have lower yarn tenacity for the tested samples. In addition to the frictional properties, the length and fineness of fibres should also be considered for assessing the spinnability of fibres. An indicator for extensive dyeing is the micronaire value; it becomes larger after dyeing, mostly due to shrinkage and swelling on the cross section of the fibre. In fact, it was noticed that the micronaire values had a tendency to be larger for the dark coloured fibres.

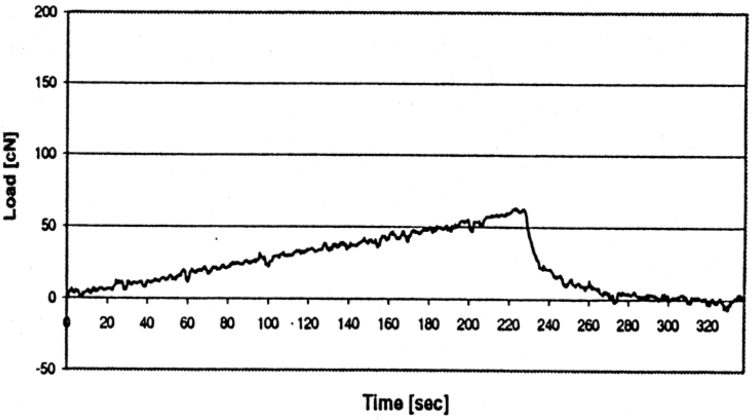


**Figure 9.** Compression curve of Golden Wheat colour cotton sample

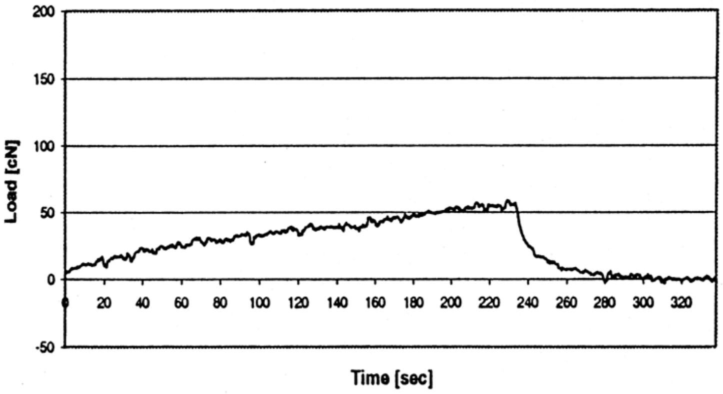


**Figure 10.** Compression curve of Kelly Green colour cotton sample

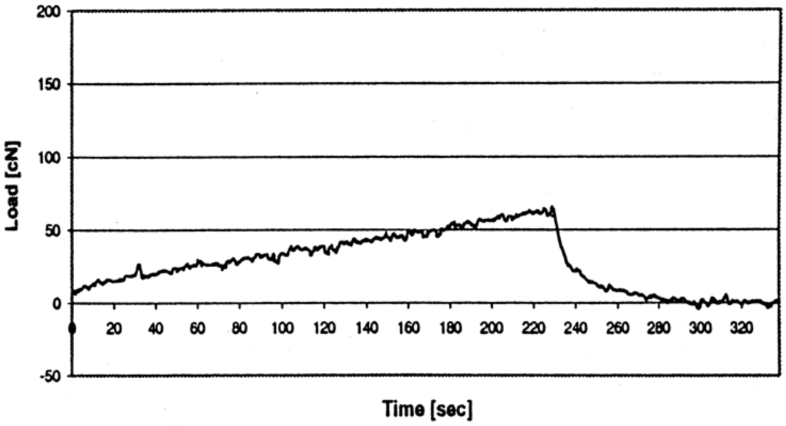


**Figure 11.** Compression curve of Orange colour cotton sample

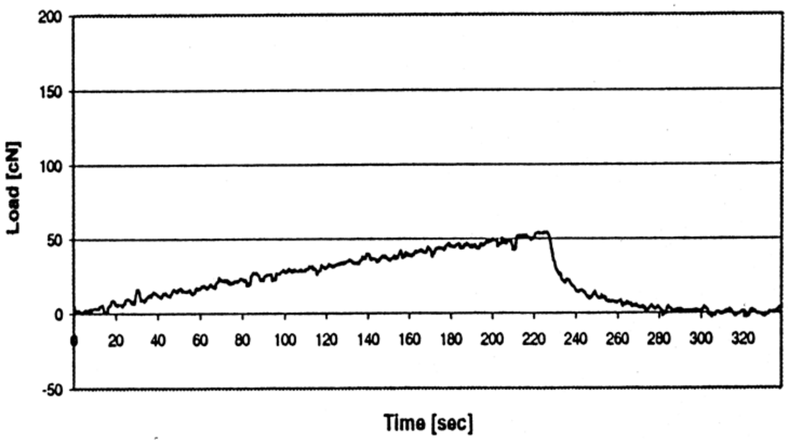


**Figure 12.** Compression curve of Rose colour cotton sample

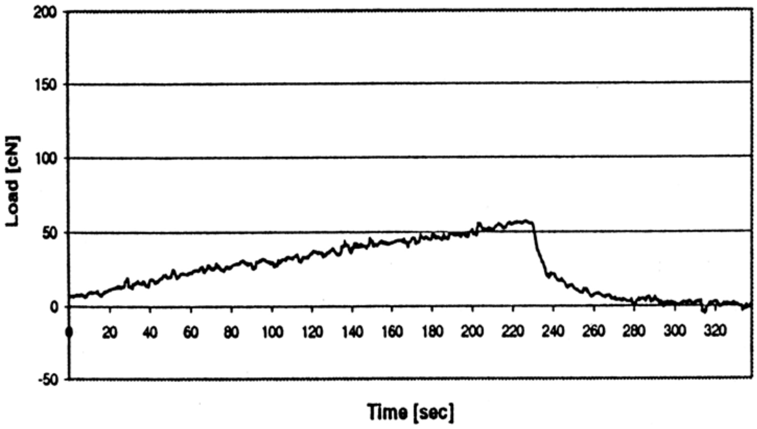


**Figure 13.** Compression curve of Sage colour cotton sample

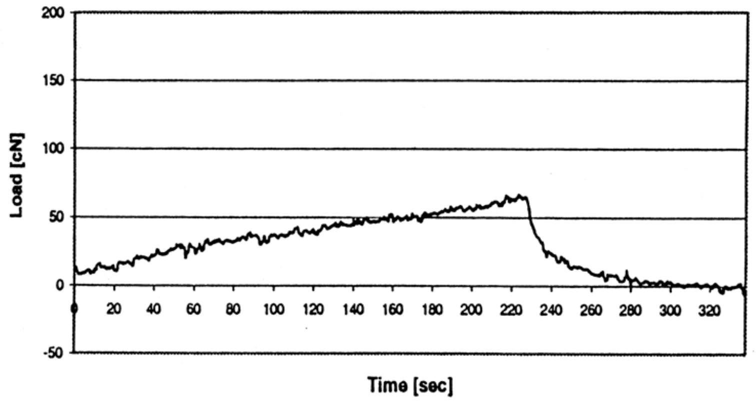


**Figure 14.** Compression curve of Yellow colour cotton sample

## 4. CONCLUSION

In the reported experiment, a new friction tester was evaluated by using cotton fibres with different colours. It was not surprising that the dye type would change the surface properties of fibres. As seen in Table 1, the maximum compression force by itself has many distinct characteristics for different types of fibres. It was possible to distinguish the fibre types by using the developed friction tester. However, it is necessary to construct a testing method and data interpretation, in conjunction with the testing, to predict the behaviour of fibre during the spinning process.

A quick glance of the data given in Table 1 suggests that the observed values are smaller for light coloured cotton than those of dark coloured cotton. Most of the dark coloured samples gave start-up breaks during spinning, and the total score of the number of breaks was larger than the light coloured ones. The measured compressive force tended to be large for the dark coloured samples. One reason to have a large compressive force for the dark coloured fibres may be the following:

- The dyeing time for the dark colours is usually longer than the light colours, and
- The longer time can cause more swelling for fibres.

In fact, the linear density measurement gave a larger value for dark coloured fibres. Since the cross-section of the dark coloured fibres was larger than that of the light ones, the true contact area of the dark coloured fibres was also greater than that of the light coloured fibres. Consequently, a larger contact area introduces a higher compression force for the dark coloured samples due to the fact that friction is dependent on the contact area for the fibrous materials. Examining the figures for the dark and light coloured fibres shows that the bouncing effect of the compression curve is related to the colour of the fibres. As seen in Figure 3 through Figure 14, dark coloured fibres required higher compression load than the light coloured ones.

As a conclusion, it is possible to predict the spinability of cotton fibres by using the friction testing instrument. The instrument also seems promising in behaviour prediction of fibres during spinning because the behaviour of fibres in the drafting zone is strongly related with the surface characteristics of fibres. However, it is necessary to perform a large number of tests to construct a suitable algorithm for spinnability of a particular fibre type. There are numerous factors affecting the spinnability of fibres, some of which are directly related to the physical properties of fibres, such as, fineness and length. Therefore, it would be necessary to prepare some charts and tables to give a score for the overall expected spinnability of fibres. These charts and tables should combine currently measurable properties of fibres (by using HVI and/or AFIS) with the data from the friction tester.

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