TECHNIQUES TO ASSESS YARN TENSILE PROPERTIES

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Abstract

The availability of high-speed tensile testing machines has made it possible to predict yarn performance more accurately. However, results obtained from new, high speed testing machines do not show the same results as those from older, slow speed testing machines. The testing machines used were USTER®Tensojet, USTER®Tensorapid, and Constant Tension Transport by Lawson-Hemphill. The data presented is from 21different yarns which were spun on three different spinning systems from 7 different cotton/polyester blends, together with 29 other cotton and cotton/polyester yarns. The method of yarn analysis was developed by evaluating the yarn data. Single-strand breaking tenacity and breaking elongation was measured for each yarn. Testing speed was considered as a possible factor influencing the tenacity-elongation characteristics in a yarn. The experimental results obtained show that the tenacity value obtained from the various test increases linearly with the logarithm of the testing speed.

Introduction

The tensile characteristics of yarn are defined as "the characteristics of measured resistance of a material to stretching in one direction". The measured tensile properties are characterized quantitatively by the Breaking Force $F_{max}[cN]$, Breaking Tenacity $F_{max}/tex[cN/tex]$, Coefficient of Variation of the Breaking Force $CV_{Fmax}[\%]$, Breaking Elongation $E_{Fmax}[\%]$, and Work-to-break $W_{Fmax}[cN*cm]$.

Until recently, the most common approaches for obtaining these tensile characteristics were based on the traditional "simple pull test"(SPT), in which the thread is subjected to a relatively slow rate of load or extension, which is usually slower than found either in processing or in final end use. Lea Strength Testing is the traditional method of assessing yarn strength and at the same time checking the count of the yarn. This is still the standard method of some companies, particularly in USA, although it has been superseded in most places by single-thread testing. Single-thread testing is usually based on testing a 50cm sample of a yarn at either a constant rate of extension or a constant rate of loading. Scott Skein Tester, Instron Single Column, Zwick 1511, USTER®Tensorapid, USTER®Tensojet, and Textechno Statimat are testing machines which use the testing principle of constant rate of extension. USTER Dynamat II tester is an example of the testing machine which uses testing principle of constant rate of loading. The two testing principles are fundamentally different in the way they test the yarn sample. In a constant rate of loading tester, the time to break is held approximately constant by adjusting the rate of loading. Therefore, the rate of extension and the percent extension per minute are variable. However, in a constant rate of extension tester, the time to break is variable. At a fixed rate of extension, the percent extension per minute is constant. All of the testers based on the two testing principle offer a wide variety of information related to the breaking load, breaking elongation and work to rupture of a yarn. This information gives a guide to the relative performance of one yarn against another in the fabric making processes and with this information one is able to detect yarns that are totally unsuitable.

Another big difference among those testers is the testing speed. Tensojet, the most recently developed testing machine, can perform at a maximum speed of 400 m/min. It can carry out 30,000 tests per hour, in other words, more than 8 tests per seconds. This is an incredibly higher speed compared to other testing machines, such as, for example Tensorapid (maximum speed is 5 m/min). Krause has already mentioned that a large number of tensile tests are required and the development of a high-speed tensile testing machine makes it possible to thoroughly analyze the mechanical properties of the yarn. However, in earlier research it was found that there were some differences in tenacity and elongation values obtained when using high-speed testing machine as compared to low-speed testing machine.

Luca and Thibodeaux were the pioneers to show analytically how low or high speed testing affects yarn tenacity. They used USDA Acala cotton as a test sample and the tested speeds ranging from 0.1 m/min to 5 m/min. They found that as the rate of extension increased, yarn tenacity increased linearly with the logarithm of the rate of extension from 0.1 to 1 m/min. At 2 m/min, yarn tenacity increased slightly, reached a maximum, and then at 5 m/min, it decreased or remained constant. However, there are several limitations in their research. They only tested speeds ranging from 0.1 to 5 m/min, which are relatively low speeds compared to the testing speed of the Tensojet. Also, they used 100% cotton yarn which has larger deviation than the blended yarns or man-made yarns.

One of the main purposes of this current research is to compare newer testing machines with older ones. The other purpose of the research is to try to obtain a deeper understanding on what factors lead to the difference in results which may be obtained from the different testing machines.

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Apparatus

In this experiment three of the most widely used yarn tensile testing machines, were selected. These were: Uster®Tensojet, Uster®Tensorapid, and Constant Tension Transport (CTT) by Lawson-Hemphill. To verify that testing speed can lead to differences in the results, the MTS®Sintech was also used.

USTER®Tensojet

Introduced in 1992, USTER®Tensojet is used for testing the tensile strength of textile staple-spun yarns. It clamps and tests 50cm yarn samples within the force range of 0.7N to 50N and the elongation range of 3 to 70 percent. Tensojet is a CRE--Constant Rate of Elongation--tester. Basically, Tensojet extends the test material until it breaks and thereby determines the physical values of tensile force and elongation. Then the other values such as tenacity and work done are determined from those values and the yarn linear density. With the high speed of 400 meters per minute, it takes only 60 minutes to test 24 kilometers of yarn. This is considered an incredibly high speed when compared with other testing machines.

USTER®Tensorapid 3

USTER®Tensorapid 3 is another CRE--constant rate of elongation--textile testing machine. While Tensojet tests only staple-spun yarn, the Tensorapid is claimed to be suitable for single yarns, ply yarns, fiber assemblies, woven strips and yarn hanks. This wide range of application can explain why it is still being used so popularly despite its slow speed (maximum 5 m/min) in comparison with Tensojet. This testing machine, in common with the Tensojet, consists of four units which are the tester, the creel, the signal processor, and the printer.

Constant Tension Transport (CTT)

Constant Tension Transport (CTT) is a unit developed by Lawson-Hemphill. This CTT machine measures breaking strength of a yarn dynamically. As for a speed range, there are two ranges of speed built-in to the CTT-Basic Unit system, which are continuously adjustable in 1 to 10 m/min increments. CTT basically does two things; determines the breaking force and finds the weak places. To find weak places, test material is simply run at increasing tensions until yarn-breaks occur. In finding weak places in yarns using CTT, every millimeter of yarn is tested. This is one of the key advantages of the CTT unit and explains why it is considered a dynamic testing method.

MTS®Sintech

MTS®Sintech is another textile testing machine using software called TestWork™. It is composed of three parts which are testing, analyzing, and data managing. MTS®Sintech operates in the same way basically as the Tensorapid in that two clamps hold specimen using compressed air and extend it until it breaks. The differences are that the speed is much slower than the two USTER machines (maximum 0.5 m per minute) and this machine is manual since individual specimens are mounted then tested and then the next sample is mounted, etc. However, when the test starts, MTS®Sintech shows real-time display on the screen.

Experiment

Tensile testing was carried out in three parts. The preliminary trials were performed by testing various kinds of yarns --cotton, acrylic, poly/cotton yarns—using Tensojet, Tensorapid, and Constant Tension Transport (CTT) by Lawson-Hemphill. Measured properties were Breaking-force, Elongation, Tenacity, and Work-force. For Tensojet, within one test, 1024 tests were performed and the testing speed was 400 m/min. For Tensorapid, 50 tests within one test were performed and the testing speed was 5 m/min. To make the testing conditions similar to those of the Tensojet, the length between the clamps was set to 50 cm, and pre-tension was 0.5 cN/tex. For CTT, the maximum speed, which is 360m/min, was used as the testing speed. Following the procedure set out in the operating manual, all the tests started with a low tension, that could be survived easily by the sample. Then by increasing tension by 10 grams for each test, Breaking Tension (BT) was found. However, to find as accurate a BT as possible, 5 tests above and below the BT were performed. For the determined BT, the average elongation value was recorded.

To investigate the tensile behaviors of poly/cotton yarns further, the final trials were performed by testing 21 different poly/cotton blended yarns. Twenty-one yarns were made using various blend ratios of cotton and polyester as well as different kinds of spinning methods. Using Tensojet and Tensorapid, the tensile properties of each yarn were measured and the testing machines were compared.

The last part of tensile testing was done to evaluate the correlation between the tenacity and the testing speed. Various testing speeds were applied using Tensojet (400, 100, 50 m/min), Tensorapid (5, 2, 1 m/min), and MTS®Sintech (0.5 m/min).

Results and Discussion

To investigate how the yarns react differently according to the different testing machines, the preliminary trials were done by testing cotton, acrylic, and poly/cotton and the results are shown in Figure 1 to 6. As shown in Figure 1 and 3, Tensojet shows the higher value of yarn tenacity than Tensorapid. Also, in Figure 5, in the case of 100% cotton, the tenacity value from the Tensojet is consistently higher than that from the Tensorapid. However, in the case of 50/50 poly/cotton, the tenacity value did not show the same trend as that of 100% cotton. It was also found that the elongation values from the Tensorapid are 1% to 1.5% higher than those from the Tensojet.

As demonstrated in Figure 5, 50/50 poly/cotton behaved differently from 100% cotton and acrylic. For further investigation of the behavior of 50/50 poly/cotton, 29 jet spun poly/cotton yarns were tested and the results are displayed in Figure 7 and 8. As indicated in Figure 7, the tenacity value from Tensojet and Tensorapid has revealed no significant difference. This is the same trend as shown in Figure 5 in 50/50 poly/cotton samples. However, the elongation value revealed the consistency illustrated in Figure 2, 4 and 6.

Figure 9 and 10 are the correlation graphs between Tensojet and Tensorapid that were plotted from the data used in Figure 5 and 6. It was shown possible to obtain a stronger correlation of the elongation value than that of the tenacity between the two testing machines.

As mentioned earlier, the testing principles of the Tensojet and Tensorapid are basically the same but their testing speeds are different. It is claimed that the CTT tester is also a high-speed testing device and it was considered useful to determine whether the data obtained from Tensojet and Tensorapid could be related to CTT. It should be noted that the speed of CTT is not the speed of extending the sample like in the Tensojet and Tensorapid but the speed of front and back rollers.

To compare Tensojet & Tensorapid and CTT, twenty-nine yarn samples were tested. Among them, 19 samples were 100% cotton and the rest of them were 50/50 poly/cotton. Figure 11 and 12 are the correlation graphs obtained from Tensojet and CTT. As indicated in Figure 11 and 12, the correlation of the tenacity value is stronger than that of the elongation. Also, 100% cotton and 50/50 poly/cotton showed different correlation in the case of elongation.

It should however be noted that while there is a clear correlation between the strength value from the Tensojet and CTT testers, there is a difference in the absolute value. The reason for the difference could be partly due to the lower sensitivity of the CTT and also is probably associated with the fact that the breaking tension is a reflection of the minimum yarn strength whereas the data used from the Tensojet is the average yarn strength. The same explanation is applied to the comparison between the Tensorapid and CTT. Therefore, when comparing the tenacity value between the Tensojet & Tensorapid and CTT, the data from the Tensojet and the Tensorapid should be re-evaluated by taking the minimum tenacity values among the data points. These re-evaluated comparisons between the two machines are plotted in Figure 13 and 14.

For a further investigation of the tensile behaviors of poly/cotton yarns, the final trials were performed by testing 21 different poly/cotton blended yarns. Figure 15, 16 and 17 demonstrate how 7 different blended poly/cotton yarns react differently in the Tensojet and the Tensorapid when they are spun in 3 different ways. As shown in three figures, the tenacity values from the Tensojet are higher than those from the Tensorapid. These results are the same as those revealed in preliminary trials. Generally, the data from the yarns spun in air-jet showed the least difference from those other yarns spun in different spinning system. Also, the difference between the Tensojet and the Tensorapid becomes the least when the blend ratio is 50%. These results correspond to the exceptional behaviors of 50/50 poly/cotton in the preliminary trials.

The data mentioned earlier shows differences in the tenacity measured by different machine, although the same yarn samples were tested. In searching for the cause of the differences, different testing speed of each machine was considered. The effect of testing speed on measured tenacity showed the expected trend, i.e., as testing rate increased the force required to break the yarn also increased. Since textile materials are visco-elastic, it is a well-known fact that their tensile properties are rate dependent.

To assist this suggestion, the measurement of tenacity according to the testing speed was performed for the 7 kinds of poly/cotton yarns made by ring spinning system. Among the test results, the results of 100% cotton and 50/50 poly/cotton are illustrated in Figure 18. To determine tenacity as a function of testing speed, MTS Sintech was used for speeds below 0.5 m/min, and Tensorapid for speeds from 1 m/min to 5 m/min, Tensojet for speeds above 100 m/min. All the data points are fitted to a linear function. As the percentage cotton increases there is an increased deviation of the tenacity from linearity. Therefore, it is clearly demonstrated that the force depends on the testing speed and that the amount of force is proportion to the logarithm of the speed.

These results are different from those of Luca and Thibodeaux, Salhotra and Balasubramanian, and Kaushik *et al*. They found that yarn tenacity increasing on up to a certain testing speed. However, in this research, the yarn tenacity shows a continuous increase with the logarithm of the testing speed.

Based on these results, it is possible to correlate the data from CTT and Tensojet & Tensorapid. As demonstrated earlier in re-evaluated graph Figure 13 and 14, there is still some difference between the minimum value from Tensojet and CTT as well as Tensorapid and CTT. That difference can be explained by the testing speed difference between the two machines. As mentioned before, the actual extension rate of CTT is near zero, whereas, those of Tensojet and Tensorapid are 400 m/min and 5m/min respectively. Considering these speed differences, we can finally re-evaluate the tenacity value between the two machines. Figure 19 and 21 are the re-plotted Tensojet and Tensorapid minimum data based on the equation obtained from Figure 18 (i.e. a “correction” has been applied to compensate for testing speed). With this correction, there is little difference between the re-adjusted Tensojet & Tensorapid data and the CTT data. Figure 20 and 22 are the correlation graphs from the data obtained by re-evaluation of the speed factor. As indicated in the linear function in Figure 20 and 22, it is noted the better correlation between the Tensojet-CTT, Tensorapid-CTT after re-evaluation of speed factor.

Figure 23 is the overall comparison among the all three testing machines. As shown in Figure 23, the final re-evaluated Tensojet data matched the CTT data more closely than the Tensorapid data even though the tenacity difference between the raw data from the Tensorapid and CTT were less than the other. However, when we compare the both of the correlation coefficient values, there is not enough evidence to say that there is significant difference among the three different testing machines. But, to catch out the weakest spot in the yarn which is important in production process, the Tensojet is better than the Tensorapid.

Conclusions

The main purposes of this current research were to compare newer testing machines with older ones and to investigate possible factors that cause any tenacity difference between the different testing machines.

The comparisons were made among the three tensile testing machines (Tensojet, Tensorapid and Constant Tension Transport (CTT)). It was found that different testing machines yielded differences in the measured tensile properties. For tenacity, the values from Tensojet are generally higher than those from Tensorapid. However, it is clearly shown that poly/cotton responds differently. For elongation, the values from Tensorapid are higher than those from Tensojet. The trend was consistent across all the samples tested in this research. Also, it is shown to be possible to correlate the data from Tensojet & Tensorapid and CTT even though the testing principles are fundamentally different. Tensojet and Tensorapid data should be readjusted by the speed factor in order to compare it with the CTT tenacity value.

From above findings, the testing speed was considered as a possible factor for the difference in results between the testing machines use. As expected, a relationship between tenacity and testing speed exists. It was also found that the tenacity is proportional to the logarithm of testing speed.

References

Textile Terms and Definitions. The 8th Edition. The Textile Institute.

Douglas, K. What Is Meant by Yarn Specification? Knitting Technique, July, P274-274, 1991.

Zellweger Uster, Uster Statistics 1989, Zellweger Uster, Switzerland, No.36, October, 1989.

Bauer-Kurz, I., Lee, E.K., and Oxenham, W., An Assessment of Techniques Used to Determine the Tensile Behavior of Cotton Yarns. A Report to Cotton Incorporated. May, 1997.

Parker, A., Yarn-The strengths and Weaknesses. Textile Month, P25, 27-28, 31, March, 1993.

Krause, H.W., and Soliman, H.A., Technological Evolution in Weaving - Do Higher Machine Speeds Require Better Yarns? Proceedings West-European Textiles Tomorrow, P235-259, 1990.

Vangheluwe, ir.L., and Bacque, Ing.K., Analysis of Deviations in Tensile Tests Results. Melliand Textilberichte, E242- 243, November, 1995.

Oxenham, W., An Assessment of Techniques Used to Determine the Tensile Behavior of Cotton Yarns. A Report to Cotton Incorporated, September, 1995.

De Luca, L.B., and Thibodeaux, D.P., Comparison of Yarn Tenacity Data Obtained Using the Uster Tensorapid, Dynamat II, and Scott Skein Testers. Textile Research Journal, 62, No.3: P175-184, March, 1992.

Salhotra, K.R., and Balasubramanian, P., Effect of Strain Rate on Yarn Tenacity, Textile Research Journal, 55, P74-75, (1985)

Kaushik, R.C.D., Salhotra, K.R., and Tyagi, G.K., Influence of Extension Rate and Specimen Length on Tenacity and Breaking Extension of Acrylic/Viscose Rayon Rotor Spun Yarns, Textile Research Journal, 59, P97-100, (1989).

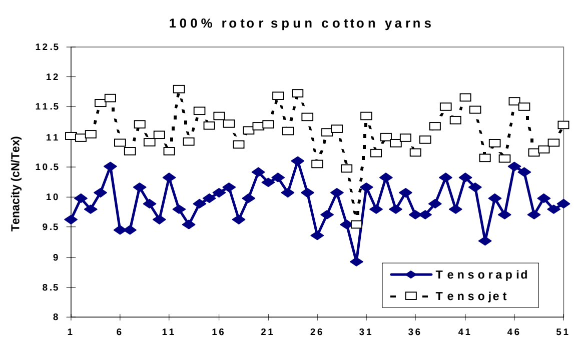

Figure 1. The comparison of the tenacity values obtained from the Tensojet and the Tensorapid in 100% rotor spun cotton yarns.

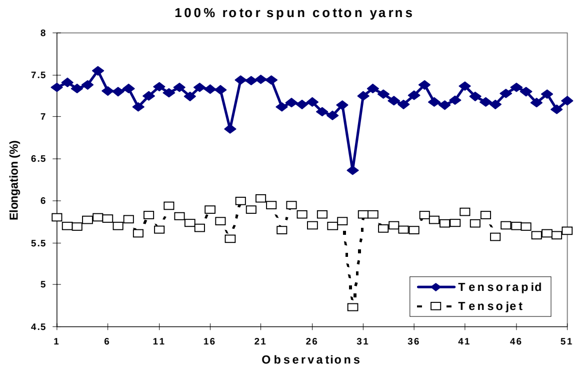

Figure 2. The comparison of the elongation values obtained from the Tensojet and the Tensorapid in 100% rotor spun cotton yarns.

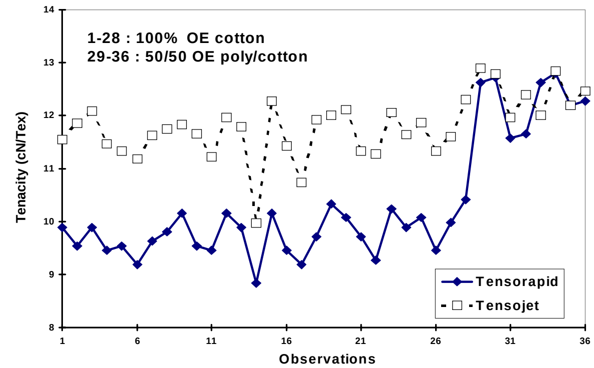

Figure 5. The comparison of the tenacity values obtained from the Tensojet and the Tensorapid in 100% cotton and 50/50 poly/cotton yarns.

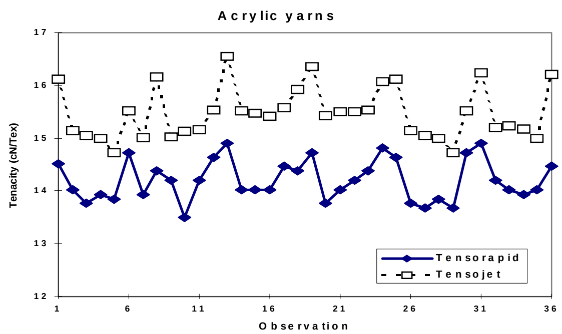

Figure 3. The comparison of the tenacity values obtained from the Tensojet and the Tensorapid in acrylic yarns.

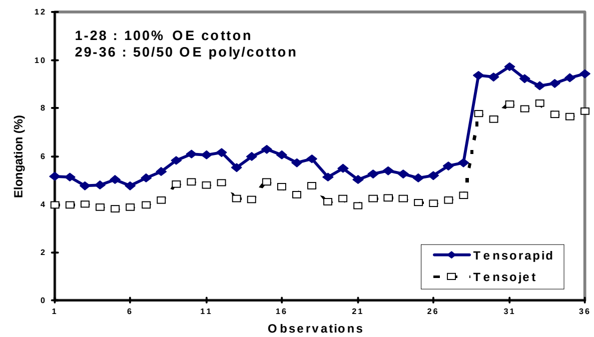

Figure 6. The comparison of the elongation values obtained from the Tensojet and the Tensorapid in 100% and 50/50 poly/cotton yarns.

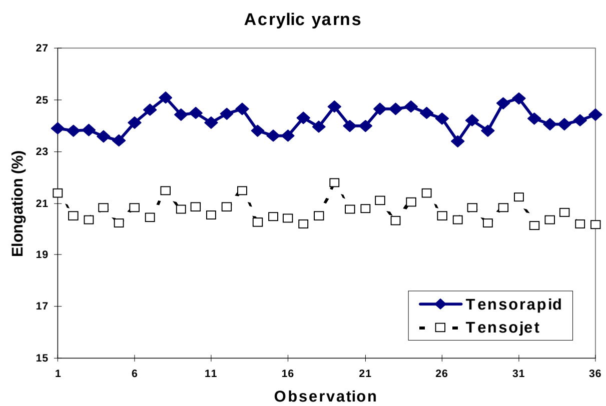

Figure 4. The comparison of the elongation values obtained from the Tensojet and the Tensorapid in acrylic yarns.

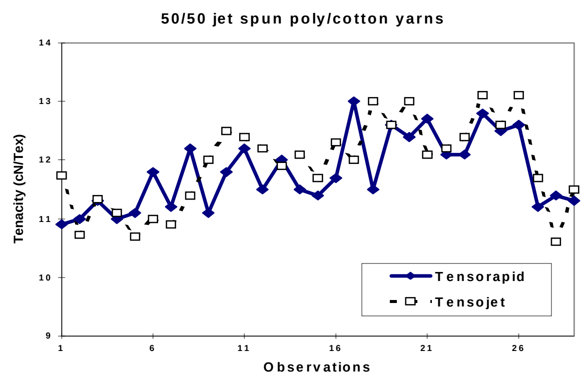

Figure 7. The comparison of the tenacity values obtained from the Tensojet and the Tensorapid in 50/50 jet spun poly/cotton yarns.

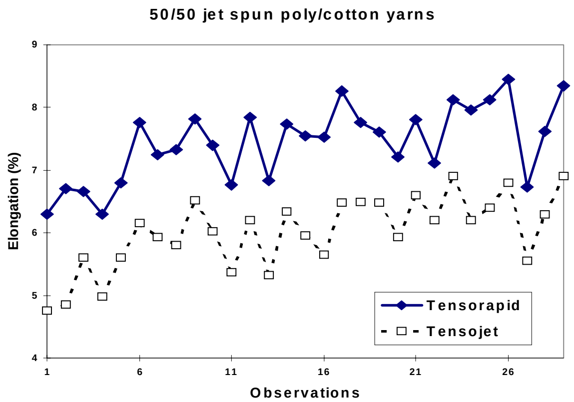

Figure 8. The comparison of the elongation values obtained from the Tensojet and the Tensorapid in 50/50 jet spun poly/cotton yarns.

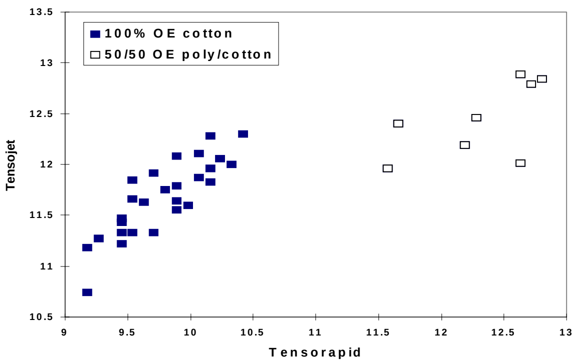

Figure 9. The correlation of the tenacity values between the Tensojet and the Tensorapid in 100% cotton and 50/50 poly/cotton yarns.

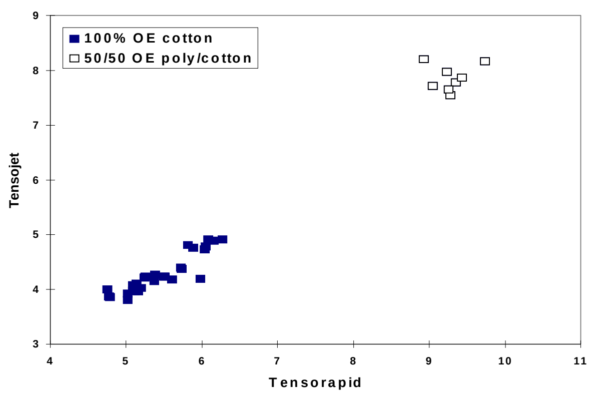

Figure 10. The correlation of the elongation values between the Tensojet and the Tensorapid in 100% cotton and 50/50 poly/cotton yarns.

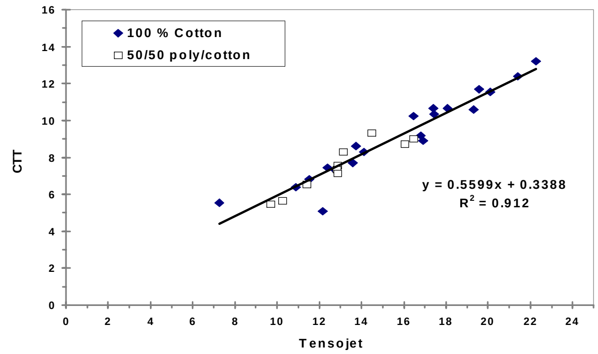

Figure 11. The correlation of the tenacity values between the Tensojet and the CTT in 100% cotton and 50/50 poly/cotton yarns.

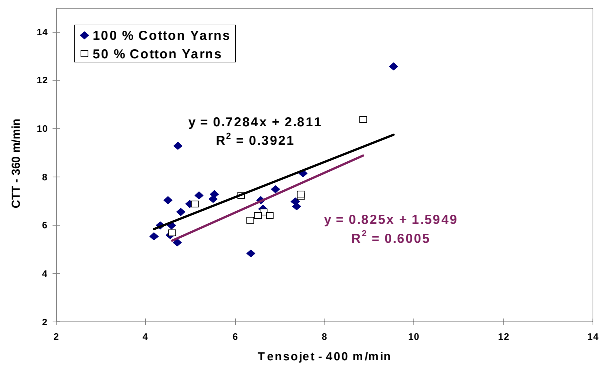

Figure 12. The correlation of the elongation values between the Tensojet and the CTT in 100% cotton and 50/50 poly/cotton yarns.

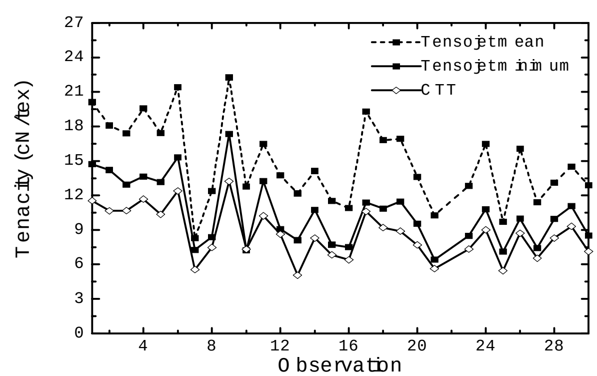

Figure 13. The comparison of the re-evaluated tenacity values between the Tensojet and the CTT.

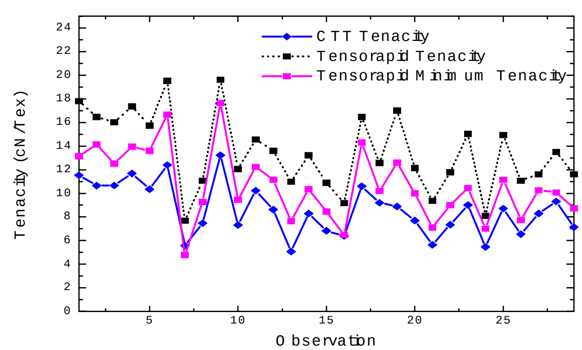

Figure 14. The comparison of the re-evaluated tenacity values between the Tensojet and the CTT.

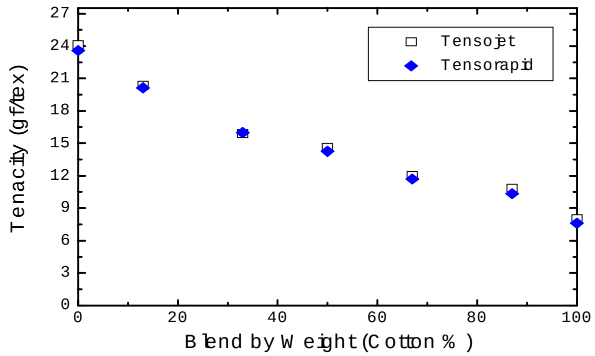

Figure 15. The comparison of tenacity values of poly/cotton air jet spun yarns between the Tensojet and the Tensorapid.

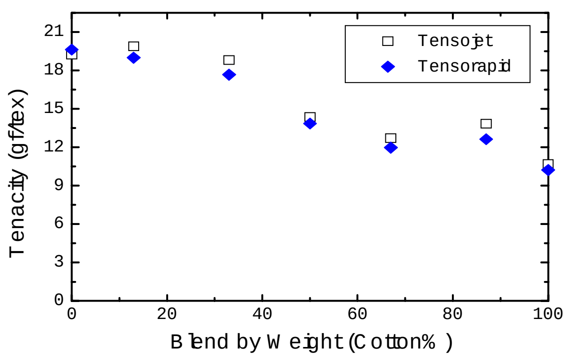

Figure 16. The comparison of the tenacity value of poly/cotton rotor spun yarns between the Tensojet and the Tensorapid.

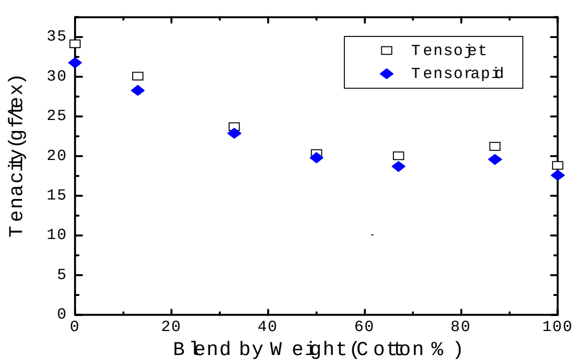

Figure 17. The comparison of tenacity values of poly/cotton ring spun yarn between the Tensojet and the Tensorapid.

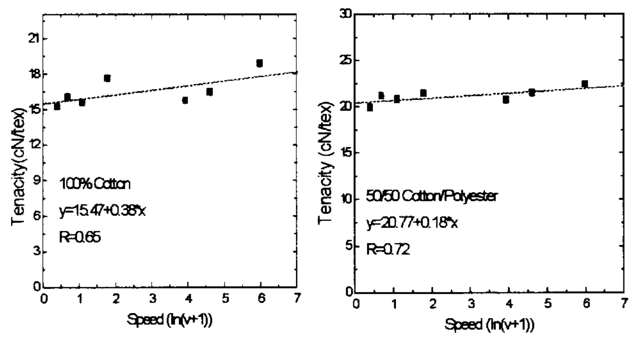

Figure 18. The relationship between the tenacity and testing speed.

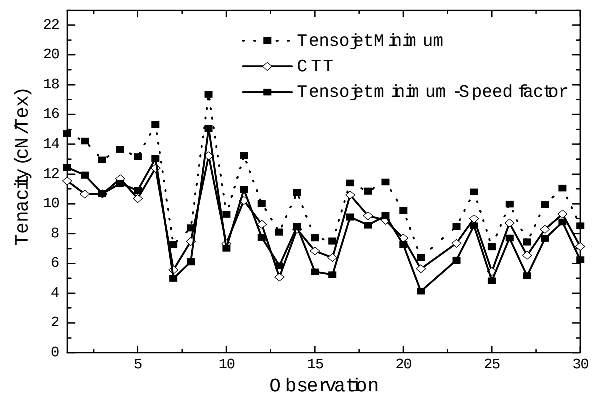

Figure 19. The comparison of the final re-evaluated tenacity value between the Tensojet and the CTT.

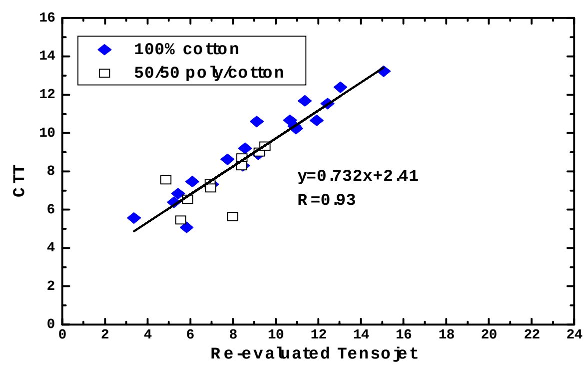

Figure 20. The correlation of the re-evaluated tenacity values between the Tensojet and the CTT.

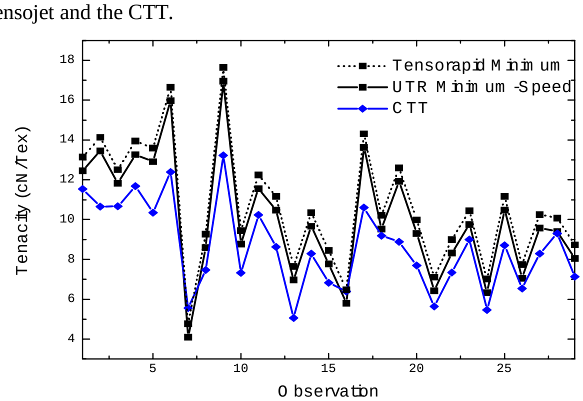

Figure 21. The comparison of the final re-evaluated tenacity value between the Tensorapid and the CTT.

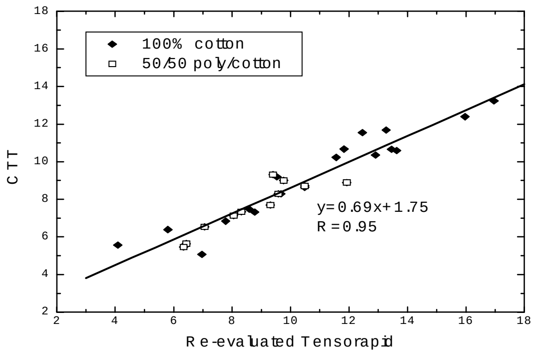

Figure 22. The correlation of the re-evaluated tenacity values between the Tensorapid and the CTT.

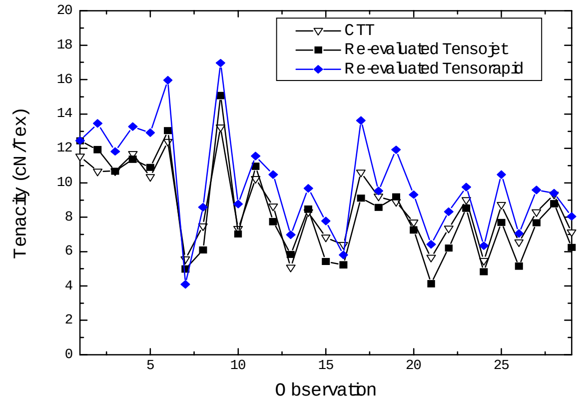

Figure 23. The comparison of the final re-evaluated tenacity value among the Tensojet, the Tensorapid and the CTT.