Relationships Between Cotton Fiber Properties and Mill Processing Results from Bale to Card Sliver

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ABSTRACT

The inherent fiber properties of cotton affect the ultimate utility value of the textile end product and the processing efficiency at each stage of converting fiber to fabric. Opening, cleaning and carding in particular, dictate the quality and productivity levels that can be achieved in manufacturing carded and combed cotton yarns through their effect on nep removal, cleaning efficiency and short fiber content. This study was to identify and describe variables that have a statistically significant impact on opening, cleaning and carding. This paper describes the efficiency of nep removal, trash removal and short fiber content from opening to card sliver for short/medium staple Upland cotton and for LS/ELS cotton.

Introduction

The inherent fiber properties of cotton affect the ultimate utility value of the textile end product as well as the processing efficiency at each stage of converting fibers into fabrics. The preparatory processes prior to actual spinning, i.e. opening, cleaning, and carding in particular, dictate both the quality and productivity levels that can be achieved in manufacturing of carded and combed cotton yarns. Certain individual cotton fiber properties, combinations of, and interactions between different fiber properties have been assumed to affect important measures of quality in spinning preparation, e.g. nep removal, cleaning efficiency, and short fiber content. The objective of this study was to identify and describe those variables that have a statistically significant impact on opening, cleaning, and carding. With this information, it is possible to quantify the contribution of both the process and the processed fiber material to determining the overall manufacturing result. It can be demonstrated that apart from high-performance equipment, profound knowledge of the functional fiber quality parameters and their effect on the preparatory processes is essential to obtain optimum results in yarn manufacturing.

Material and Methods

To identify the cotton fiber quality parameters that have a significant impact on processing, stepwise multiple linear regression techniques were applied to analyze a large set of experimental data. The data were established in numerous trials conducted in the Truetzschler research laboratories, the Truetzschler customer show room, and in the field. The data base consists of several hundred data sets. It contains information on various fiber quality parameters measured at specific processing stages from bale to card sliver and it truly represents state-of-the-art manufacturing technologies, i.e. for instance, CLEANOMAT CVT multiple cylinder cleaners and the latest model DK 803 high-performance card. The data also represent a wide spectrum of both short/medium (Upland) and long/extra-long staple cottons from international sources.

Rather than processing different cottons under identical conditions, which certainly would have facilitated the identification of the functional fiber quality parameters, the plant configuration and the settings and production speeds of the individual machines were adapted to the specific processing situation. With these two independent sources of variability, i.e. the distinct raw materials on one hand and the difference between machine setups on the other, the effect of either component on the overall processing result could be assessed separately. Moreover, varying machine setups is the only truly practical approach since no two cottons are exactly alike and no two cottons should be processed the exact same way.

In conducting the stepwise multiple linear regression procedure, the focus was clearly not on maximizing the correlation coefficient; rather, for a variable to qualify for entry into the regression equation, it had to meet stringent significance criteria. The variability introduced by the different plant configurations and machine setups is much too complex to be expressed by simple numerical variables. It was therefore treated as a collective assembly of variance. As a result, the accuracy of the regression models is somewhat limited. However, developing models for forecasting purposes was not the objective of this study. The objective was to identify the fiber properties that have a statistically significant impact on the processing results and the model building process was designed accordingly.

During the analysis of the data, it became evident that short/medium (Upland) cottons on one hand and long/extra-long staple cottons on the other represent two independent and diverse populations. Most scatter plots displayed two separate data clusters and staple

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length always qualified for entry into the regression equation. Considering the physical and technological differences between the two groups of cottons, the original data pool was divided into a short/medium staple and a long/extra-long staple data set, when needed. The cutoff staple length was 1¼ inch (31.75 mm). While the original research work covered both groups of cottons, the scope of this paper has been confined to short/medium staple cottons.

Results and Discussion

Nep removal efficiency from bale to card sliver

It has been generally acknowledged that nep levels are subjected to fairly significant changes when cotton fibers are converted from a bale into card sliver. Starting with a certain number of AFIS neps per gram in the cotton bale, their frequency normally increases by 50% to 100% or more after cleaning, i.e. in the card mat. The primary source of additional fiber entanglements is the cleaning process, where cleaning machines with different configurations of beaters, spiked cylinders, or cylinders with saw-tooth wire are employed. Nep formation, however, may also be induced by conveying fiber tufts through the duct work via air flow. Excessive lengths of straight ducts, fans, elbows, flaps, and other elements that generate surface friction or cause the tufts to perform rotational movements contribute to a greater number of neps. The card is the first machine in the mill processing sequence that efficiently reduces the number of neps.

According to the AFIS method, the overall nep reduction efficiencies from bale to card sliver range between 50% and 90% for Upland type cottons (Figure 1). The number of AFIS neps in the card sliver is always lower than the average number of neps in the bale laydown, i.e. the increase of the number of neps after cotton cleaning is more than compensated during carding, irrespective of the initial nep level. The actual nep removal percentage depends on the card throughput rate, the card settings and the main cylinder speed in particular, as well as on type and wear condition of the flats and main cylinder clothings. It also depends on some cotton-specific properties that either promote or inhibit nep removal.

With Upland type cottons, three variables qualify for entry into the regression equation for AFIS neps in the card sliver as the dependent variable:

a) AFIS nep content of the raw material

b) gravimetric trash content of the raw material (Shirley Trash Separator)

c) FMT fiber fineness of the raw material

Figure 2 displays the regression output and ANOVA tables. The qualitative effect of these raw material properties on the nep frequency in the card sliver is illustrated in Figure 3.

a) Obviously, the number of neps per gram in the card sliver decreases with lower nep counts in the raw material. This appears to be a trivial relationship but it reflects the practical experience that changes in raw material nep levels will result in proportional deviations of the number of AFIS neps per gram in the card sliver, given that all other factors remain essentially the same.

b) There is also a significant effect of the trash content of the cotton raw material on the number of neps in the card sliver. Cleaner cottons provide fewer neps in the card sliver or higher overall nep removal efficiencies from bale to card sliver. The trash content affects the nep removal efficiency in two ways: Naturally, cottons with a high trash content require more intensive cleaning, i.e. more cleaning points in the process sequence and mote knife settings which provide more effective trash removal. Both measures will inevitably cause an increase of the number of neps in the card mat and eventually in the card sliver. At the card, a high input trash content impairs the machine's ability to effectively remove neps. The clothing of the revolving flats is quickly saturated with trash particles and fibrous material that is attached to these particles, reducing the effectiveness of the carding action between the flats and the main cylinder. This can be partially compensated by increasing the flats speed. However, as a rule of thumb, the trash content of the card mat should be no higher than 1% in order to ensure proper nep removal, cleaning, and parallelization.

c) The third variable which affects nep removal is FMT fiber fineness or the mean linear density of the fiber. The coarser the cotton fibers, the lower the number of neps in the card sliver. Again, the effect of fiber fineness is twofold: Fine fibers exhibit a lower longitudinal bending rigidity. In fact, there is a quadratic relationship between linear density and bending rigidity. Hence, a 10% change in fiber fineness, for instance, provokes a 21% change in bending rigidity. As a result, fine fibers display a considerably higher nep formation propensity and they tend to form much tighter and smaller entanglements during cotton cleaning. By the same token, these smaller and tighter neps are harder to remove during carding. The second effect of fiber fineness relates to the total number of fibers processed at a given constant mass throughput, which of course is substantially higher with finer fibers. A 10% reduction of fiber fineness, for example, results in a 10% higher number of fibers to be processed in carding. Consequently, the number of points/inch^2 of the flats and main cylinder clothings which are available per one fiber, i.e. the carding intensity, decreases by 10%. This situation is equivalent to a 10% increase of the card production rate. Fully mature, high-micronaire cottons consist of relatively coarse fibers and they provide excellent nep removal efficiencies. In contrast, less mature, low-micronaire cottons lead to a higher number of neps in the card sliver. Due to the hybrid nature of the micronaire measurement, it does not always serve as a reliable indicator of fiber fineness. With most Upland type cottons, however, low micronaire is normally associated with low maturity, finer fibers, and somewhat higher nep frequencies.

Figure 4 represents a breakdown of the quantitative effect of both raw material and mechanical processing on card sliver nep frequency. It is an answer to the question as to what factors determine the neppiness of the card sliver in cotton spinning. The three raw material properties, AFIS neps per gram, gravimetric trash content, and fiber fineness account for 52% of the observed variability. Opening, cleaning, and carding contribute the remaining 48%.

Trash removal efficiency from bale to card sliver

Trash removal is the number one objective in the preparatory processes prior to spinning. However, cotton cleaning will always be a compromise between trash removal efficiency on one hand and fiber damage, loss of usable lint, and nep formation on the other. The term 'cleanability' describes an elementary cotton-specific characteristic, which to a large extent controls the overall trash removal efficiency from bale to card sliver. Cleanability itself is believed to be the product of several independent or interacting fiber properties.

In Figure 5, the residual gravimetric trash content of the card sliver is plotted over the input trash content of the raw material for short and medium staple cottons. Evidently, the overall trash removal efficiencies from bale to card sliver range between 90% and 99%, depending on both the cleanability of the cotton and the degree of cleaning during mechanical processing. Multivariate statistical analysis of the data base revealed that two fiber properties have a major impact on the residual trash content of the card sliver (Figure 6).

a) gravimetric trash content of the raw material

b) AFIS nep content of the raw material

The qualitative effect of these fiber properties is once more illustrated by the 'fiber quality mixer' (Figure 7).

a) The relationship between the trash content of the raw cotton and the card sliver is a trivial one. It simply reflects the conventional wisdom that a low input trash content will inevitably result in a low output trash content and vice versa, provided that all other factors remain unchanged.

b) The influence of the number of AFIS neps per gram in the raw material on the residual card sliver trash content is everything but trivial. Apparently, a low number of neps in the raw cotton means good cleanability. From a technological point of view, there is no sound explanation for the high degree of association between the average nep level of a bale laydown and the trash content of the card sliver. Yet, the evidence of a large number of neps in a raw cotton bale is an indirect but strong indicator of the processing history of the cotton, i.e. the stress exerted on the fiber during harvesting and ginning. This processing history of a cotton determines its cleanability. Unfortunately, the processing history of cotton can neither be measured directly nor unequivocally derived from any of the known fiber properties. However, aggressive harvesting and ginning practices are the primary reason for neps in cotton. Neps do not grow in the field but machine picking, saw ginning, and excessive lint cleaning certainly favor the formation of fiber entanglements. Aggressive harvesting and ginning does not only produce neps but the very same aggressive treatment also causes formerly large trash particles to become crushed and dispersed (pepper trash). We know that particle shape, size, and density play in important role in the mill cleaning process. In addition, it is conceivable that the same mechanism that generates neps will also lead to a situation where trash particles and fibers become tightly entangled. The physical behavior of such objects lies somewhere between that of a trash particle and a fiber. Thus, an effective separation of the resulting low-density foreign matter by means of centrifugal force becomes increasingly difficult.

In Figure 8, the factors affecting the residual trash content of the card sliver are broken down into fiber and process-related components. In general, the card sliver trash content is to a large extent a result of the degree of cleaning applied to the cotton in the mill. Consequently, 78% of the observed variability in card sliver trash content can be attributed to mechanical processing and 22% are related to fiber quality.

Short fiber content

Throughout the entire opening, cleaning, and carding process, short fibers are both removed and produced to a limited degree. In carding, for instance, a substantial amount of short fibers is separated as flat strips, but some short fibers will also be generated as a result of fiber breakage. However, the bottom line balance, i.e. the short fiber content of the card sliver, is of primary interest. Figure 9 illustrates the relationship between input and output short fiber content from bale to card sliver for both short/medium and long/extra-long staple cottons. It is important to note that the short fiber content was determined with the AFIS instrument and that the numbers represent the weight-related percentage of fibers shorter than ½ inch (12.7 mm). Evidently, the short fiber content of the card sliver deviates by ±0% to +2% from the initial short fiber content of the raw material in bale form. The observed variance of the short fiber content by weight of the card sliver can be partially explained by two statistically significant variables (Figure 10):

a) AFIS short fiber content of the raw material

b) FMT maturity ratio of the raw material

The qualitative effect of these fiber properties is visualized in Figure 11.

a) The high degree of association between the short fiber content of the card sliver and the fibrous raw material in bale form does not come as a surprise. The lower the short fiber content in the raw material, the lower the subsequent short fiber content of the card sliver. If the short fiber content of the card sliver indeed represents some kind of an equilibrium between short fibers which have been removed and generated during the entire process, then the base level of short fiber content is essentially determined by the amount of short fibers in the laydown.

b) FMT maturity ratio is the second variable to qualify for entry into the multiple regression equation. Evidently, high maturity ratio ensues a lower short fiber content of the card sliver and vice versa. Immature or dead cotton fibers, which are often associated with low micronaire values, are characterized by a rudimentary secondary cell wall, where only very small amounts of cellulose have been deposited during the growth cycle. The lack of cellulose substance causes immature fibers to develop only a low absolute tensile strength. Hence, immature cottons tend to be more susceptible to mechanical stress and they break relatively easily during processing, which will invariably result in a higher short fiber content.

In Figure 12, the factors affecting the AFIS short fiber content by weight of the card sliver are divided into the two principal categories, i.e. raw material and process-related effects. 56% of the observed variability of the short fiber content of the card sliver can be explained by the influence of the fiber properties and 44% are related to mechanical processing in opening, cleaning, and carding.

Conclusions

The outcome of this study unequivocally demonstrates that the desire to enhance both quality and productivity in the preparatory stages prior to spinning should be realized with a two-way strategy since the overall effect of fiber properties and fiber processing on the qualitative and quantitative processing result is of about the same magnitude: Part one of this strategy encompasses investing in state-of-the-art opening, cleaning, and carding technology. The recent progress made in textile machinery engineering and the technological superiority of what we can justifiably call the 'new generation' of cleaning machines and cards, does indeed provide a quantum leap towards higher quality, productivity, and lower manufacturing cost. The second part of this strategy focuses on the selection of proper raw materials and the composition of appropriate mixes with average fiber properties that guarantee optimum processing behavior and sliver quality. Selecting optimum raw materials is not necessarily a question of cost; rather, it is a question of knowing exactly what and where to look for. Both parts of this strategy represent equally effective and feasible alternatives.

Figure 1. Relationship between input/output neps (short/medium staple cottons).

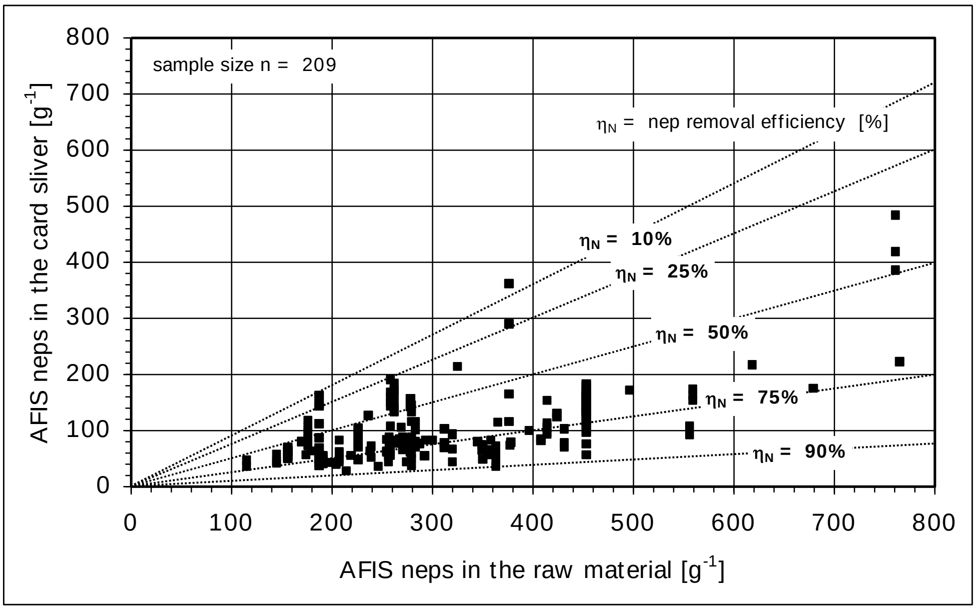

Figure 2. Regression output table (short/medium staple cottons).

DEPENDENT VARIABLE:	**AFIS NEPS IN THE CARD SLIVER [g^{-1}]**
Multiple correlation coefficient	0,719
Standard error	43,7824
No. of observations	209

SOURCE	*DF*	*SS*	*MS*	*F VALUE*	*PR > F*
Regression	3	421598,4778	140532,8259	73,3125	2,9498E-32
Residual	205	392964,9002	1916,9020		
Total	208	814563,3780			

PARAMETER	*COEFFICIENT*	*STD. ERROR*	*t VALUE*	*PR > |t|*
AFIS neps in raw material [g^{-1}]	0,2667	0,0283	9,4294	9,1786E-18
Gravimetric trash content [%]	14,1420	2,4052	5,8798	1,6477E-08
FMT fiber fineness [dtex]	-100,1792	20,4549	-4,8976	1,9653E-06

Figure 3. Factors affecting neps in the card sliver (short/medium staple cottons).

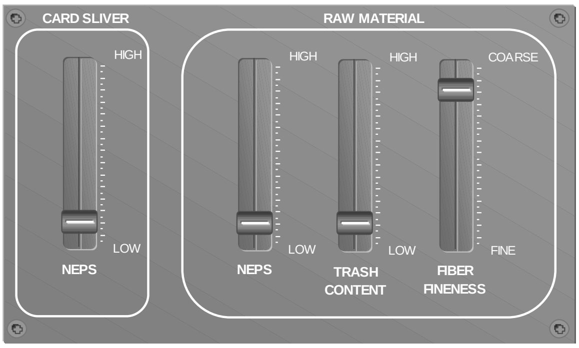

Figure 4. Effect of raw material and mechanical processing on neps in the card sliver.

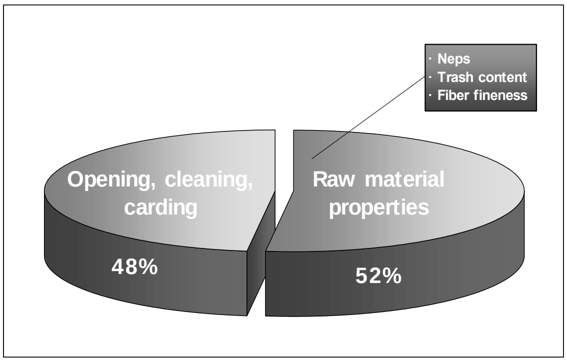

Figure 5. Relationship between input/output trash content (short/medium staple cottons).

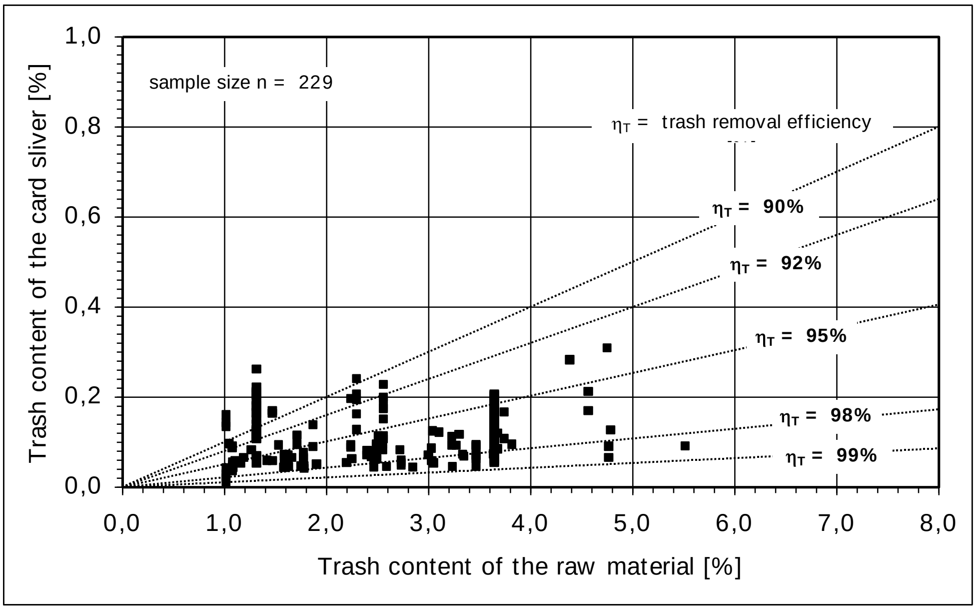

Figure 6. Regression output table (short/medium staple cottons).

DEPENDENT VARIABLE:	**TRASH CONTENT OF THE CARD SLIVER [%]**
Multiple correlation coefficient	0,465
Standard error	0,0467
No. of observations	229

SOURCE	*DF*	*SS*	*MS*	*F VALUE*	*PR > F*
Regression	2	0,1361	0,0680	31,1323	1,1425E-12
Residual	226	0,4939	0,0022		
Total	228	0,6300			

PARAMETER	*COEFFICIENT*	*STD. ERROR*	*t VALUE*	*PR > |t|*
AFIS neps in raw material [g-1]	0,0002	0,0000	6,9957	2,9598E-11
Gravimetric trash content [%]	0,0126	0,0029	4,2814	2,7463E-05

Figure 7. Factors affecting trash content in the card sliver (short/medium staple cottons).

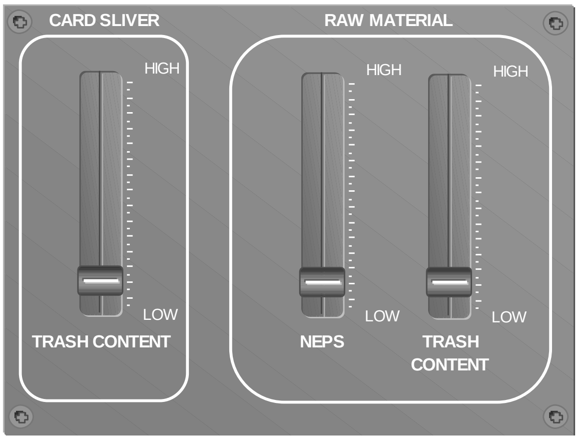

Figure 8. Effect of raw material and mechanical processing on card sliver trash content.

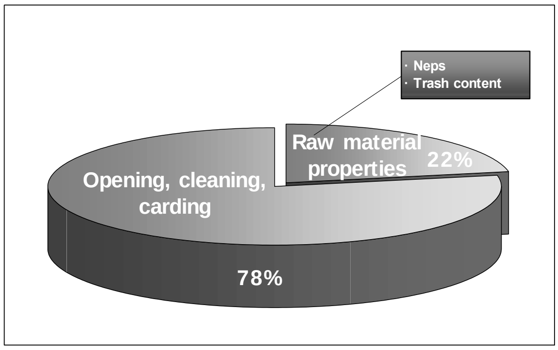

Figure 9. Relationship between input/output SFC (short/medium staple cottons).

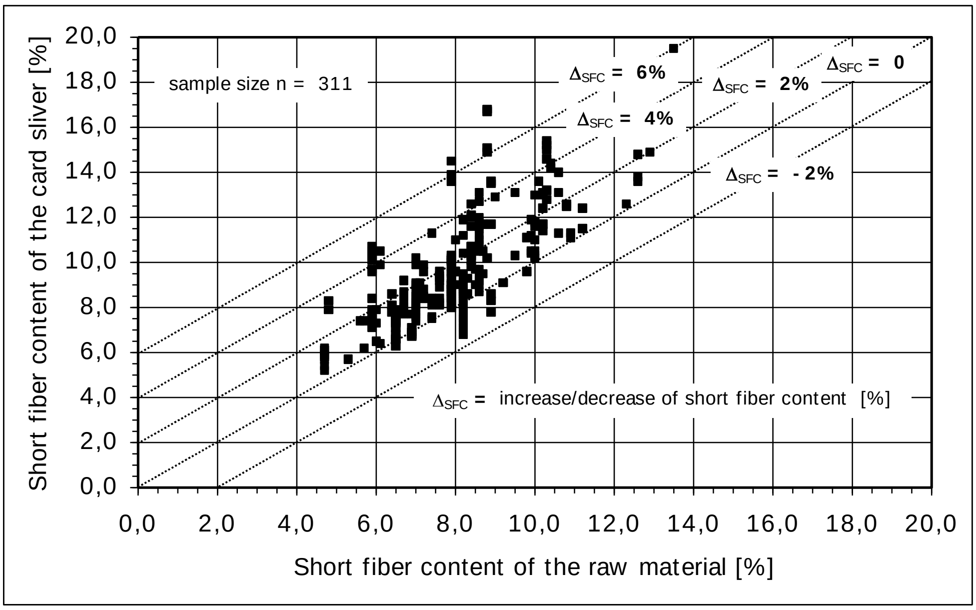

Figure 10. Regression output table.

DEPENDENT VARIABLE:	**AFIS SHORT FIBER CONTENT OF THE CARD SLIVER [%]**
Multiple correlation coefficient	0,747
Standard error	1,4958
No. of observations	311

SOURCE	*DF*	*SS*	*MS*	*F VALUE*	*PR > F*
Regression	2	869,6354	434,8177	194,3447	2,5631E-55
Residual	308	689,1046	2,2374		
Total	310	1558,7400			

PARAMETER	*COEFFICIENT*	*STD. ERROR*	*t VALUE*	*PR > |t|*
AFIS SFC in raw material [%]	0,9986	0,0600	16,6426	8,2330E-45
FMT maturity ratio [ ]	-6,7791	1,5187	-4,4637	1,1316E-05

Figure 11. Factors affecting short fiber content of the card sliver.

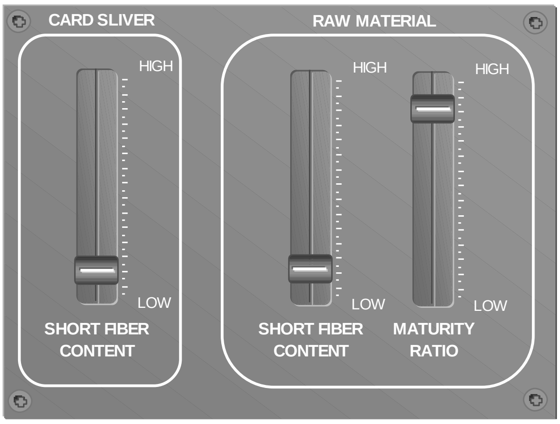

Figure 12. Effect of raw material and mechanical processing on SFC of the card sliver.