EFFECT OF MECHANICAL ACTIONS ON COTTON FIBER QUALITY AND FOREIGN-MATTER PARTICLE ATTACHMENT TO COTTON FIBERS

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Abstract

The effects of various machine-fiber interactions during harvesting and ginning on fiber quality and attachment between foreign-matter particles and fibers were studied to develop new and less damaging methods for removing foreign-matter particles from cotton fiber. In total, the study involved 75 samples collected from five locations in a field near College Station, Texas, including three replications and five different harvesting and processing treatments: (1) hand-picked and hand-ginned, (2) machine-picked and hand-ginned, (3) machine-picked, seed-cotton-cleaned, and hand-ginned, (4) machine-picked, seed-cotton-cleaned, and machine-ginned, and (5) machine-picked, seed-cotton-cleaned, machine-ginned, and one-stage lint-cleaned. A microscope was used to identify foreign-matter particles in each sample. Physical characteristics of the particles and their attachment to fibers were investigated and classified. All samples were analyzed with HVI and AFIS. Data of the particle classification, HVI, and AFIS were statistically processed with SAS. Results indicated that each machine-fiber interaction during the harvesting and ginning process had the net effect of decreasing the size of foreign-matter particles. The particles had no obvious difference in shape across the processing stages. The tightness of particle-fiber attachment, the number of neps, and the short fiber content differed significantly as a function of mechanical actions; they all tended to increase as the number of mechanical actions increased. As expected, the gin stand was a major contributor to the increase in short fiber content. The majority of the foreign-matter particles were leaves, but proportions of the particle categories changed with stages of processing. The proportion of leaf particles decreased, while the proportion of seed-coat fragments and stems increased, with an increasing number of mechanical actions.

Introduction

Literature Review

Cotton needs to go through a series of mechanical processes from being harvested in the field to being pressed into a bale at the gin. In each step of the process cotton fiber quality is affected by interactions between fiber and mechanical actions (Mangialardi, 1985). US cotton is mechanically harvested by either a cotton picker or a cotton stripper. A cotton picker uses high-speed rotating spindles to remove seed cotton from bolls of a cotton plant. Then counter-rotating doffers unwind the cotton from the spindles, and the loose cotton is blown up through a duct into a basket and subsequently formed into a module. A cotton stripper removes the seed cotton by stripping the entire boll off the plant. The cotton is then separated from the other material of the plant in the field or at a gin with mechanical cleaning devices. In comparison with hand-harvesting, machine-harvesting of cotton dramatically speeds up and reduces the cost of harvest. However, in general machine-harvesting decreases cotton fiber quality, particularly in terms of increases in nep content and lint foreign matter level (Calhoun et al., 1996; Hughs, et al., 2000; Baker and Brashears, 2000; Willcutt, et al., 2002; Baker and Hughs, 2008; Faulkner et al., 2008).

Machine-harvested cotton contains about 13 to 35% foreign matter including plant leaves, bark, stick, stem, seed-coat fragment, shale, grass, etc. (Funk et al., 2005). It is desirable for as much foreign matter as possible to be removed from cotton fiber with minimal damage of the fiber. Removal of foreign matter at the gin involves cylinder cleaners and stick machines before fiber-seed separation to remove large particles from seed cotton, and lint cleaners after fiber-seed separation to remove smaller particles that remain in the lint cotton. Two general types of lint cleaners are currently on the market, the air-type and the saw-type. The saw-type lint cleaners are most common because of their higher cleaning efficiency. In the saw-type lint cleaner, lint from the gin stand or a prior lint cleaner is formed into a batt on a condenser drum and fed onto a rapidly rotating saw-cylinder through a set of feed rollers. While the stretched fiber batt – high-speed video shows the form to actually be more like individual fiber tufts – is on the saw cylinder, it is cleaned by a combination of centrifugal force, scrubbing action between saw cylinder and grid bars, and gravity assisted by an air current (Anthony and Mayfield, 1994).

Seed cotton and lint cleaning are necessary steps in the ginning process. However, it is also widely realized that they, particularly lint cleaning, create fiber damage. For instance, Mangialardi (1985) found that the seed-cotton drying and cleaning system and the gin stand produce neps. Furthermore, the saw-type lint cleaner damaged fiber in creating neps and reducing staple length (Mangialardi and Anthony, 1998). According to Gordon and Bagshaw (2007), a fixed-batt saw lint cleaner caused 10% to 20% increase in the nep level, 0.3 to 0.4 mm reduction in the upper quartile length by weight, and a significant increase in short fiber content, depending on varieties ginned. The longer and finer a cotton is, the greater is the damage.

As cotton fiber quality has become more and more important on the world market, researchers have been working to find the causes of the fiber damage and to develop new methodologies and mechanical systems to reduce the damage and loss of fiber while retaining the high efficiency of the saw-type lint cleaner (Columbus 1985; Baker, 1987; Hughs et al., 1992; Rutherford et al., 1999; Anthony and Griffin, 2001; Gordon and Bagshaw, 2007). Many improvements have been made in saw-type lint cleaner manufacturing over the years, but today we still use basically the same cleaning principles that were developed in the 1940s (Baker et al. 1992).

To explore the possibility of inventing a new fiber cleaning device that is significantly different from “saw and bar” processing, it is critical to develop a fundamental understanding of the nature of cotton lint and foreign matter and their physical, chemical, and possibly even electrical interactions before and during the cleaning process. One way to do this is through microscopic examination of foreign matter and its interactions with cotton fiber. Morey et al. (1976a) used stereomicroscopy and bright-field microscopy to examine botanical composition of Shirley Analyzer waste from machined-picked and machine-stripped seed cotton. Bark content ranged from 32 to 52% of the total waste amount, and cotton-leaf and weed particles were major components. It was observed that seed cotton contained a larger proportion of bark and leaf materials than lint did before lint cleaning. Using the same method, Morey et al. (1976b) determined the type of trash materials present in lint before and after saw-type cleaning, and whether lint cleaning selectively removed any of the botanical components. As the size of particles decreased, the proportion by weight of bark and leaf increased, and the content of seed-coat fragments decreased. They found lint cleaning to be ineffective at reducing the proportion by weight of leaf particles, but heavier materials like stem particles were reduced in proportion. While the work of Morey et al. was aimed at illuminating the botanical composition of trash particles in cotton and not at the way those particles are attached to the fiber, it does indicate that much can be learned through microscopy on foreign-matter particles in cotton fiber.

Objectives

1. To determine effects of mechanical actions on the type and size of foreign matter particles, on particle-fiber attachment, and on cotton fiber damage at each stage of machine processing from harvesting through ginning;
2. To determine the differences among various particle types regarding particle-fiber attachment.

Materials and Methods

Sample Collection and Analysis

The methods used in this work for sample collection and preparation were basically the same as those reported by Thomasson et al. (2009), since this work was the continuation of that research project. Cotton samples were collected from five locations of a field near College Station, TX in 2007. The five locations were indentified and selected with a soil-EC map under consideration of cotton quality variability within the field. Five treatments representing various processing stages of the cotton were involved in the experimental design. Each treatment was replicated three times. In total there were 75 samples (5 field locations, 5 treatments, and 3 replicates).

Treatment 1: Hand-harvested and hand-ginned (referred to as HH). Samples of seed cotton were hand-harvested at the five locations and were hand-ginned, representing fiber prior to mechanical interaction.

Treatment 2: Machine-harvested and hand-ginned (referred to as MH). Samples were collected from cotton harvested by a cotton picker at the five locations. These samples were also hand-ginned, and they represent fiber that has undergone mechanical interaction with the harvester only.

Treatment 3: Machine-harvested, seed-cotton-cleaned, and hand-ginned (referred to as MSH). The modules made from the cotton harvested in the same field locations were ginned at a commercial gin. Samples that were collected at the feeder apron were hand-ginned, and they represent fiber that has undergone mechanical interactions with the harvester and seed-cotton-cleaning equipment in the gin.

Treatment 4: Machine-harvested, seed-cotton-cleaned, and machine-ginned (referred to as MSM). As the modules described in treatment 3 were ginned, Samples were collected immediately after fiber-seed separation, and they represent fiber that has undergone mechanical interactions with the harvester, the seed-cotton-cleaning equipment in the gin, and the gin stand.

Treatment 5: Machine-harvested, seed-cotton-cleaned, machine-ginned, and one-stage lint-cleaned (referred to as MSML). Samples from the modules were collected after one stage of lint cleaning, and they represent fiber that has undergone mechanical interactions with the harvester, the seed-cotton-cleaning equipment in the gin, the gin stand, and one saw-type lint cleaner.

For each sample, the sub-sampling procedure involved removing a randomly selected portion of lint weighing 2.0 to 2.3 g. The subsamples were placed under a Caltex Scientific LX100 digital video microscope (Irvine, CA). Fifty randomly selected foreign-matter particles were manually removed with delicate tweezers from most of the lint subsamples, and particular attention was paid to minimizing the number of fibers removed with the particles. There were nine subsamples from which fewer than fifty particles were removed, because the total number of visible particles contained in them was less than fifty. All the particles in those nine subsamples were removed for particle classification. Each particle was identified as belonging to one of 7 categories: leaf, stem, bark, seed-coat fragment, shale (lining of the bur), stick, and grass. Each particle was assigned a two dimensional shape that best described it: rectangular, square, triangular, or round. Each particle was also measured for length in two dimensions. While being removed, each particle was subjectively assigned to a category regarding strength of attachment to the fiber (low to high was represented by the numbers 1 through five, respectively) and the level regarding number of fibers attached (low, medium, high, respectively). After the 50 particles (except for the aforementioned nine subsamples) had been removed and categorized, all remaining visible particles were carefully removed, and then the mass of all foreign-matter particles was measured.

All 75 samples were analyzed at Cotton Incorporated to determine the effect of mechanical interactions, from harvesting through ginning, on fiber quality. Fiber quality parameters including neps and short fiber content were measured with AFIS and HVI tests.

Data Analysis

Averages of particle measurements for each sample and treatment were calculated, including the ratio of trash to fiber mass, proportion of foreign-matter types, dimensions of the particles, tightness of particle-fiber attachment, and level of number of fibers attached to the particle. One-way ANOVA and a Tukey Post-hoc test were conducted with SAS to compare the effects of mechanical interactions on particle-fiber attachment, nep content, and short fiber content.

Results

Objective 1

The percentage of particles of the various types of foreign matter and the mass ratio of trash to fiber varied among the processing stages (table 1). The majority of foreign matter particles were leaf in all the processing stages, with very high percentages in the MH (93%) and MSH (88%) samples. In the MSM and MSML samples the proportion of leaf particles decreased while the proportion of the stem and seed-coat fragment particles increased. This occurrence could be attributable to breaking of stems and creation of seed-coat fragments by the gin stand during fiber-seed separation. After lint cleaning, the majority of particles remaining in the lint were leaf and seed-coat fragment particles, a fact consistent with the results of Boykin et al. (2009). It is also apparent that hand-ginning led to a substantial amount of seed-coat fragments, as they were 19% of the total amount of particles in the HH samples (table 1). The MH samples had the highest trash-to-fiber mass ratio (10.93%), and the ratio decreased with additional processing. It was obvious that hand-harvested cotton was much cleaner than machine-harvested.

Table 1. Types of foreign-matter particle and the ratio of trash to fiber mass across treatments.

Treatment	Foreign particle type (n) (%)							Trash by mass (%)
	Leaf	Stem	Bark	Seed-coat	Shale	Grass	Stick	
HH	72	1	3	19	3	1	1	2.93
MH	93	1	2	1	1	0	2	10.93
MSH	88	4	2	1	1	1	3	5.24
MSM	59	12	7	16	4	1	1	6.12
MSML	59	10	5	22	3	0	1	2.14

The foreign matter particles had no obvious difference in distribution of shapes among the processing stages (table 2). However, particle size decreased as cotton went through more and more machine-processing stages. The relative importance of fracturing of particles vs. selective removal of larger particles is unknown. In samples from MH through MSML, the additional stages of mechanical action reduced the number of low-level number of attached fibers from 93% to 52% and increased the number of medium and high levels from 6% to 41% and 1% to 7%, respectively. This suggests that the number of fibers attached to a particle increases with increasing mechanical action, but it is still unclear what roles are played by removal of easy-to-remove particles vs. increasing the difficulty to remove each particle. Furthermore, more mechanical processing stages were associated with more tightness of attachment between particles and fibers (figure 1). A one-way ANOVA test revealed that tightness of particle-fiber attachment differed significantly among processing stages ($F(4, 70) = 75.71$, $p < 0.0001$). Tukey post-hoc comparison of the five processing stages (table 3) indicated that MSML samples had significantly higher particle-fiber tightness ($M = 2.13$, $SD = 0.20$) than the other sample types. The tightness of MSM samples ($M = 1.87$, $SD = 0.26$) was significantly higher than that of the HH, MH and MSH samples. The tightness of MSH samples ($M = 1.27$, $SD = 0.10$) did not significantly differ from that of MH and HH samples. The tightness of HH samples ($M = 1.43$, $SD = 0.22$) was significantly higher than that of MH samples ($M = 1.16$, $SD = 0.07$). This fact could be due to the larger proportion of seed-coat fragments in the HH samples (table 1). Tighter particle-fiber attachment was generally associated with seed-coat fragments.

Table 2. Distribution of tightness of particle-fiber attachment, level of number of fibers attached to particle, particle shape, and particle dimension across treatments.

Treatment	Tightness (1-5)	Level of Attached Fibers (%)			Particle Shape (%)				Dimension (mm)	
		Low	Med	High	Square	Rectangular	Triangular	Round	X	Y
HH	1.43	80	7	13	11	58	21	10	3.32	1.62
MH	1.16	93	6	1	12	57	21	10	3.70	1.86
MSH	1.27	88	11	1	10	62	20	8	3.37	1.39
MSM	1.87	63	32	5	14	59	17	10	2.96	1.24
MSML	2.13	52	41	7	11	64	17	8	2.58	1.07

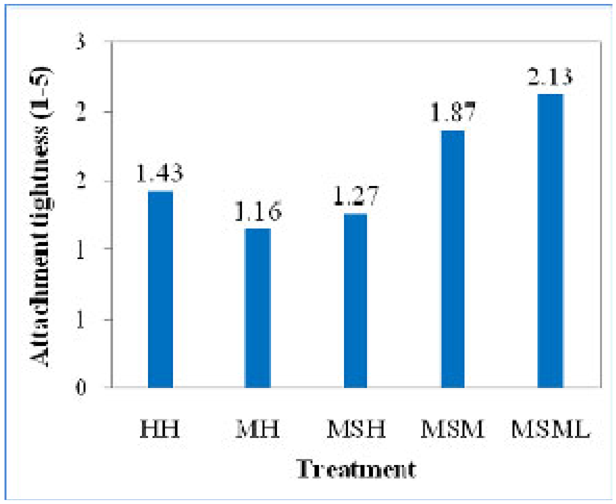

Figure 1. Mean of tightness of attachment between foreign-matter particles and fiber among various processing stages.

Table 3. Effect of the mechanical actions on the tightness of particle-fiber attachment. Means with the same letter are not significantly different.

Treatment	Mean of tightness	Std dev	N of obs.	Tukey grouping
HH	1.4300	0.2193	15	a
MH	1.1560	0.0702	15	b
MSH	1.2680	0.0997	15	a, b
MSM	1.8667	0.2588	15	c
MSML	2.1282	0.1972	15	d

Results in this study suggest that each cotton processing stage creates neps (figure 2). An ANOVA test showed that the nep content differed significantly as a function of increasing mechanical actions ($F(4, 70) = 473.82$, $p < 0.0001$). Tukey post-hoc comparison across the processing stages indicated that the mean number of neps of MSH samples ($M = 150.73$, $SD = 26.86$) was significantly higher than that of HH ($M = 54.26$, $SD = 16$) and MH samples ($M = 72.8$, $SD = 17.87$). The number of neps of MSM samples ($M = 264.93$, $SD = 25.40$) was significantly higher than that of MSH samples, and the number of neps of MSML samples ($M = 338.60$, $SD = 21.22$) was significantly higher than that of MSM samples (table 4). Comparing nep content among nearby processing stages, it was found that the dryer and seed cotton cleaners, gin stand, and the first saw-type lint cleaner caused 107%, 76%, and 28% increases in nep level, respectively.

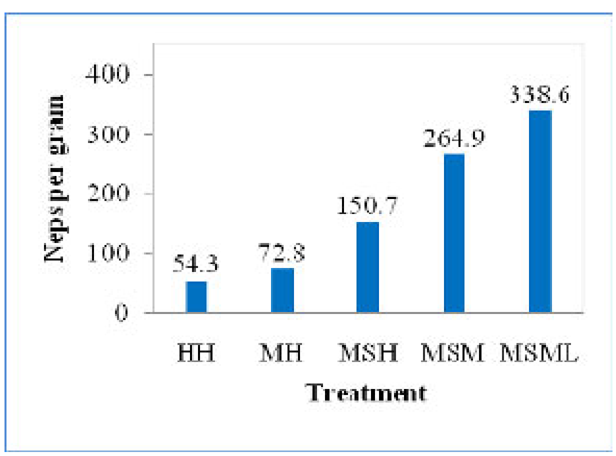

Figure 2. Nep content across the treatments. Every mechanical action during cotton processing produced neps.

Table 4. Effect of the mechanical actions on the nep content. Means with the same letter are not significantly different.

Treatment	Mean of neps (cnt/g)	Std dev	N of obs	Tukey grouping
HH	54.26	16.00	15	a
MH	72.80	17.87	15	a
MSH	150.73	26.86	15	b
MSM	264.93	25.40	15	c
MSML	338.60	21.22	15	d

A one-way ANOVA test indicated that the effect of mechanical actions on short fiber content (SFC) was also significant ($F(4, 70) = 51.40$, $p < 0.0001$). The SFC of MSH samples (M=10.62, SD=3.34) was significantly higher than that of HH samples (M = 3.89, SD = 1.64) (table 5). The SFC of MSM samples (M = 21.02, SD = 6.81) was significantly higher than that of MSH samples as well (figure 3). It was observed that the gin stand was a major contributor to SFC, producing nearly a 100% increase of SFC (10.62% to 21.02%) during fiber-seed separation. Though seed-cotton cleaning was associated with an increase in SFC, the effect was not statistically significant. The SFC of MSM samples was about the same as that of MSML samples. This fact could possibly be attributed to similar levels of creation and removal of short fiber by the lint cleaner.

Table 5. Effect of the mechanical actions on the short fiber content. Means with the same letter are not significantly different.

Treatment	Mean of SFC (w) (%)	Std dev	N of obs	Tukey grouping
HH	3.89	1.64	15	a
MH	7.83	2.20	15	a, b
MSH	10.62	3.34	15	b
MSM	21.02	6.81	15	c
MSML	20.92	4.84	15	c

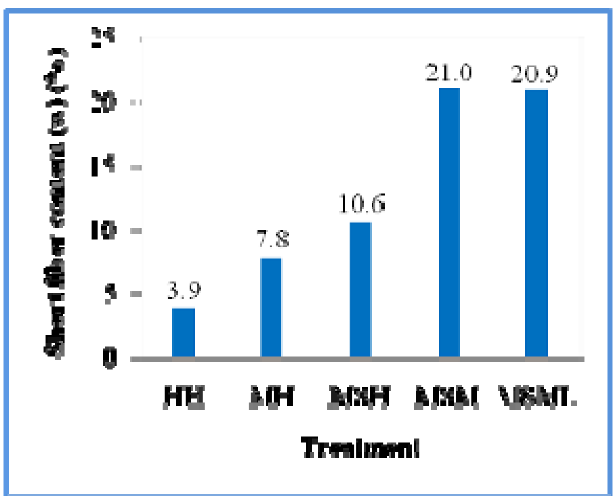

Figure 3. Short fiber content of the lint at each processing stage.

Objective 2

Upon considering the effect of particle type on tightness of particle-fiber attachment and number of fibers attached to a particle (table 6), seed-coat fragments had the highest tightness index of 2.81 (figure 4). Sticks were second highest (2.44), followed by bark, shale, and stem particles which had very similar tightness (1.71-1.77). Leaf and grass particles were attached to the fiber most loosely, with a tightness index of 1.3.

Table 6. Type of foreign-matter particle versus the tightness of particle-fiber attachment and level of number of fibers attached to particle.

Particle type	Particle amount	Average tightness (1-5)	Average attached fiber level (%)		
			Low	Medium	High
Bark	130	1.71	73	25	2
Grass	21	1.33	86	14	0
Leaf	2683	1.34	85	14	1
Seed-coat	402	2.81	14	50	36
Shale	87	1.76	71	27	2
Stem	218	1.77	73	26	1
Stick	43	2.44	40	58	2

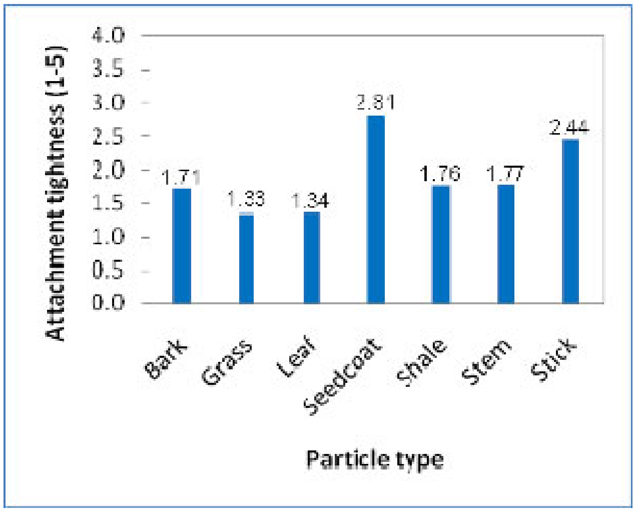

Figure 4. Tightness of particle-fiber attachment of various particle types.

In terms of the effect of particle type on the number of fibers attached to a particle, seed-coat fragments and sticks had greater numbers of fibers attached than the rest of the particle types (table 6, figure 5). In general, the least number of fibers were attached to leaf and grass particles. The number of fibers attached to bark, shale, and stem particles was at a medium level compared to seed-coat and stick group and the leaf and grass group.

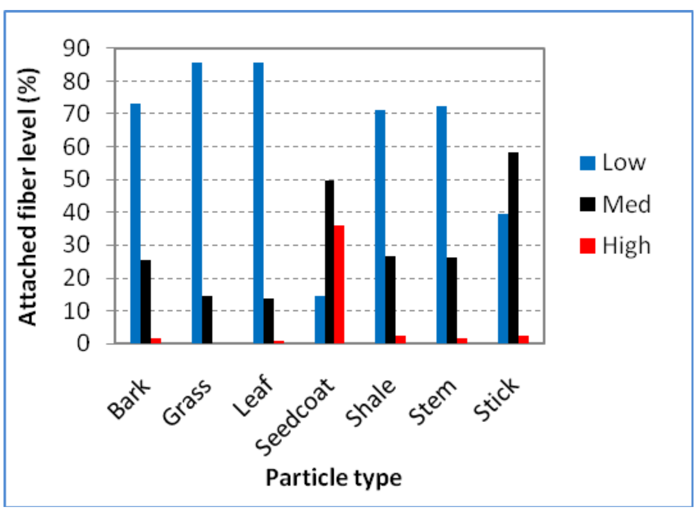

Figure 5. Effect of foreign-matter particle type on the level of number of fibers attached.

Discussion and Conclusion

The distribution of foreign-matter particle shape showed no obvious difference among various processing stages. Particle size decreased as number of the mechanical interactions increased. Leaf was the major component of foreign matter in cotton across all processing stages. With an increasing number of mechanical interactions the proportion of leaf in total foreign-matter particles decreased and the proportions of seed-coat fragments and stems increased. This fact could be due to an increase in tightness of particle-fiber attachment caused by the mechanical interactions, or it could be due to the possibility that each processing stage removes easy-to-remove particles and leaves the more difficult-to-remove particles. Mechanical interactions had a statistically significant effect on particle-fiber tightness of attachment. Tightness increased with an increasing number of the mechanical interactions. The number of fibers attached to the particle also tended to increase as the cotton went through more processing stages. The effect of mechanical interactions on nep content and SFC was also statistically significant. In comparing nep content between nearby processing stages, the mechanical interactions of seed-cotton cleaning, fiber-seed separation, and lint cleaning were associated with 107%, 76%, and 28% increases in nep content, respectively. Comparing SFC before and after fiber-seed separation, the gin stand was associated with a 98% increase in SFC.

Seed-coat fragment and stick particles were more tightly attached to the fiber than the other foreign-matter particles such as the bark, shale and stem. Relatively speaking, the leaf and grass particles were more loosely attached to the fiber and easier to remove. Along the same lines, more fibers were attached to seed-coat fragments and stick particles than to the other types of foreign-matter particles. Smaller numbers of fibers were found to be attached to leaf and grass than to bark, shale, and stem.

In measuring tightness of particle-fiber attachment and number of fibers attached to particles, the fibers that are physically attached to the seed-coat fragment were not considered separately from fibers biologically growing out of the seed-coat fragment; i.e., all fibers attached to a seed-coat fragment particle were counted as attached fibers. Considering this, it is possible that stick particles would have the highest tightness index of particle-fiber attachment and the greatest number of the fibers attached. This might be determined if the fibers growing out of seed-coat fragments were not counted as attached fibers in classifications.

This study has helped develop a fundamental understanding of the effect of mechanical interactions with cotton on physical characteristics of foreign-matter particles, particle-fiber attachment, and fiber quality. However, due to the great difficulty of accurate quantitative measurements, the critical factors such as tightness of particle-fiber attachment and number of fibers attached to a particle were determined subjectively (1 to 5 for the tightness index; low, medium, high for the number of fibers attached). With a view to developing new methods for cleaning cotton that reduce fiber damage, quantitative measurements of these factors might be more illuminating. More research is also needed to determine how foreign-matter particles are physically, chemically, and even electrically attached to fiber at various processing stages.

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