Defective fibers in wet-lay nonwoven fabrics

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Defects caused by logs, dumbbells, and ropes can be diagnosed and reduced.

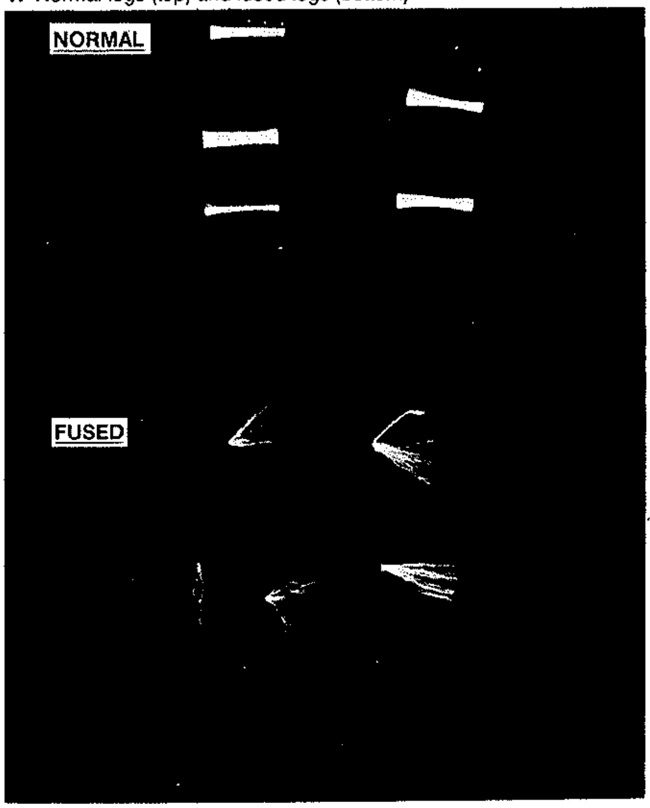
A defect-free wet-lay nonwoven fabric requires near perfection in both the fiber supply and the formation mechanics of the wet-lay process. For example, there are approximately 9.4×10^6 synthetic fibers per square meter in a typical 40-g/m^2 fabric containing 50% polyester filaments [fiber length, 12.7 mm (0.5 in.); fiber diameter, 1.5 denier]. Any one of these fibers can form a defect under the proper conditions. Put another way, 99.999989% perfection in the fiber system isn't good enough. This article discusses the different types of fiber defects, examines the fiber or equipment characteristics responsible for creating these defects, and suggests methods for minimizing defect formation.

There are three major types of wet-lay nonwoven fabric defects (*1*, *2*):

- Logs or sticks—bundles of fibers with aligned cut ends that never dispersed (**Fig. 1**).
- Dumbbells—paired clumps of fibers connected by one or more long fibers (**Fig. 2**).
- Ropes—assemblages of fiber, with unaligned ends, that are clearly more agglomerated than the general dispersion (**Fig. 3**).

Each defect type has different causes, equipment responses, and remedies.

1. Normal logs (top) and fused logs (bottom)



Logs

Undispersed logs are either a fiber supply problem or the result of gross under-agitation during initial dispersion. This brief description of logs and the kinetics for their dispersion is based on information from other sources (*3*, *4*).

Synthetic fibers are generally supplied as chips of cut fibers. These chips are dispersed by the shear forces in a pulper or stirrer tank. **Figure 4** illustrates the forces acting on a fiber during dispersion. F_s is the shear force of the liquid pulling the fiber off the log into the dispersed state. This force is resisted by $F\sigma$, the surface tension force, by $F\mu$, the friction force, and by F_f, the force caused by any fiber-to-fiber fusing (either at the ends, or along the length). When the shear force exceeds the resistance forces, all is well, and the chip will disperse if stirred long enough. If shear forces do not exceed resistance forces, the log is stable in this shear field, and infinite patience in the stirring process will not prevent the chip from causing a log defect in the fabric.

Figure 5 illustrates log dispersion rate for a 6.3-mm-long first-generation polyester (T-790) as a function of mixing time and mixer rpm. The breakup curve is divided into two regimes:

- An initial decrease, indicating that logs are breaking up (F_s exceeds resistance forces).

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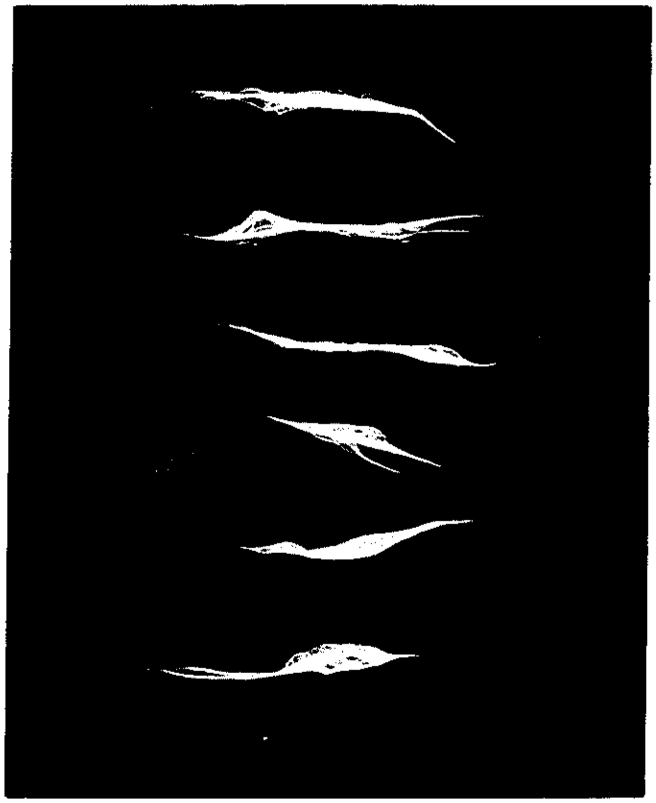
2. Dumbbells

3. Ropes



- A constant value, indicating that the remaining logs are stable in the shear field and are no longer breaking up (F_s less than resistance forces).

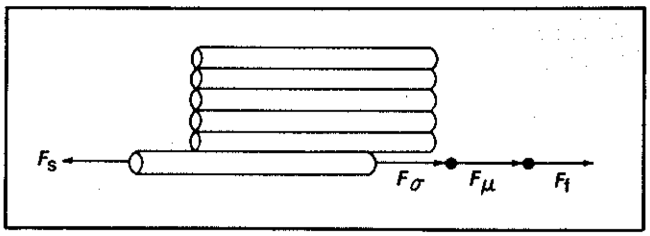
As agitator speed is increased, shear force increases, thus increasing log breakup rate and decreasing the number of shear-stable logs that do not disperse with time. In practice, the dispersion time for a given agitator speed is chosen to exceed the decreasing portion of the curve. This prevents large changes in log concentration from occurring when there are small changes in dispersing conditions.

Fiber type also has a powerful effect on log dispersion rate. **Figure 6** compares the number of log defects for a generation I polyester (T-790) and a generation II fiber (T-257W) with improved surface size (finish) and fiber characteristics. The significantly lower number of log defects in the generation II fibers illustrates the improvements made in the newer fibers.

Fiber diameter (denier per filament) is a somewhat weaker variable. Dispersion rate generally improves as denier increases. The fiber cut length has a weak effect on dispersion rate, as seen in Fig. 6.

Log defects can be diagnosed by a dispersion test such as that suggested by Shiffler (*4*). If the number of logs decreases with time, the problem is under-agitation for the given fiber type. If recovered logs are fused, either at one end (as seen in Fig. 1) or along their entire length, the problem is obviously the fiber supply. Log defects can be minimized by subjecting fibers to adequate, well-monitored agitation during dispersion and by avoiding the use of fused fibers in the furnish.

4. Force balance for a fiber in a shear field



Dumbbells

Dumbbell defects, illustrated in Fig. 2, require two conditions for their formation:

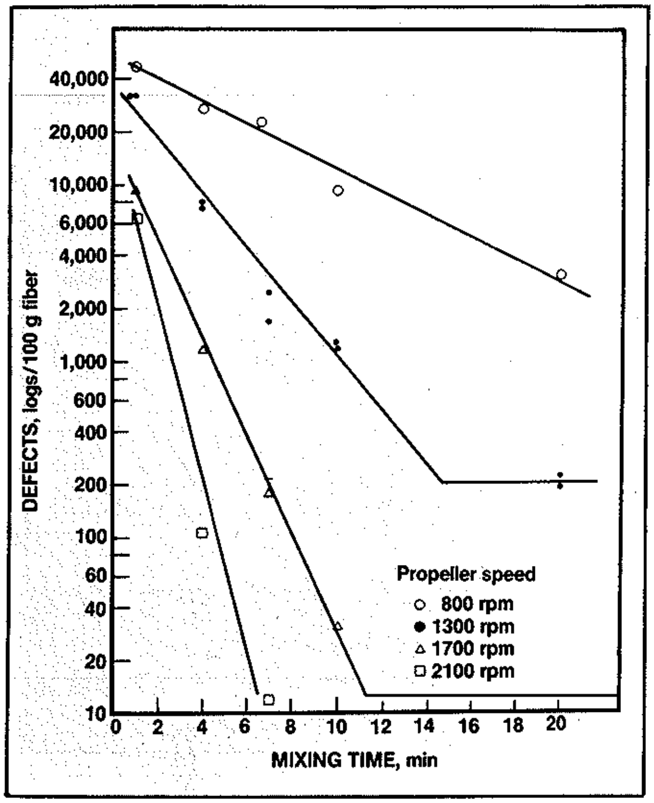
- An excessively long fiber.
- A snag in the approach piping.

Formation proceeds by the following mechanism:

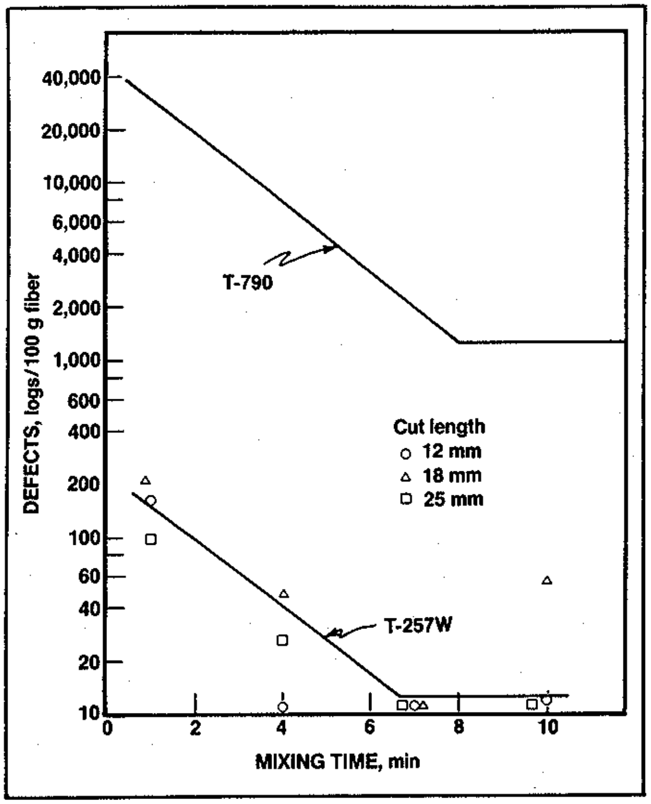
- A long fiber snags somewhere in the approach piping.
- Its free ends whip in the flow, accumulating nominal fibers on each end.
- Fiber bundles become so large that fluid drag plucks the dumbbell from the snag and delivers it to the sheet.
- The process is repeated with another long fiber.

Dumbbells can be eliminated either by eliminating excessively long fibers or by eliminating snags in the approach piping. In practice, fiber suppliers and wet-lay nonwoven producers both strive to reach these goals.

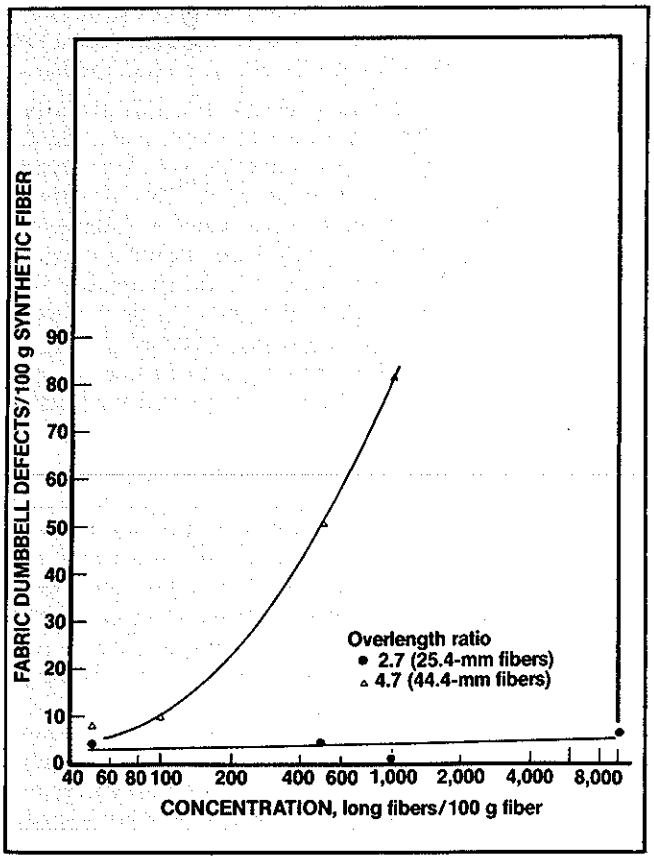
5. Effect of mixing time and agitator speed on frequency of log defects for 6.3-mm fibers. Propeller diameter = 7.9 cm; propeller pitch × 4.0



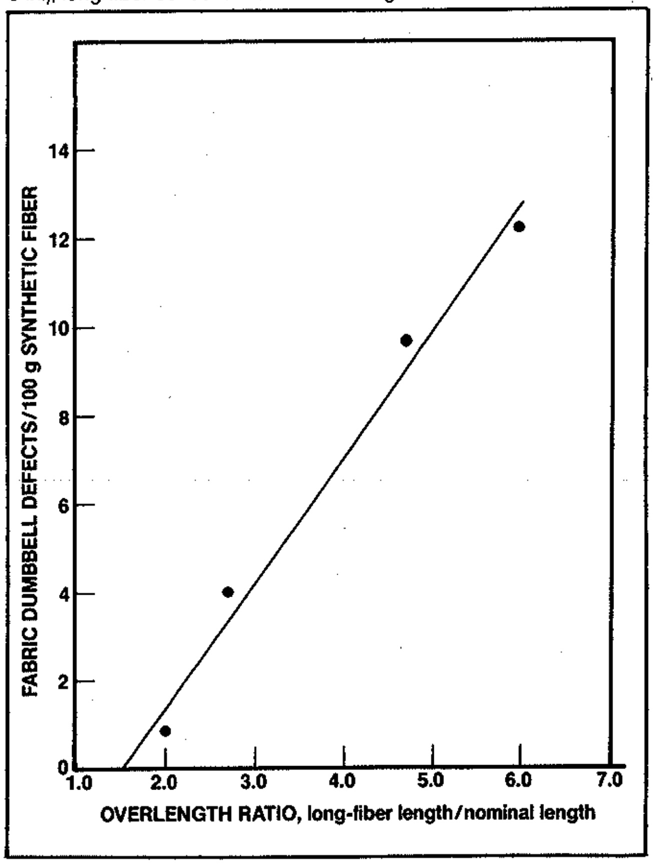
6. Effect of fiber type on frequency of log defects



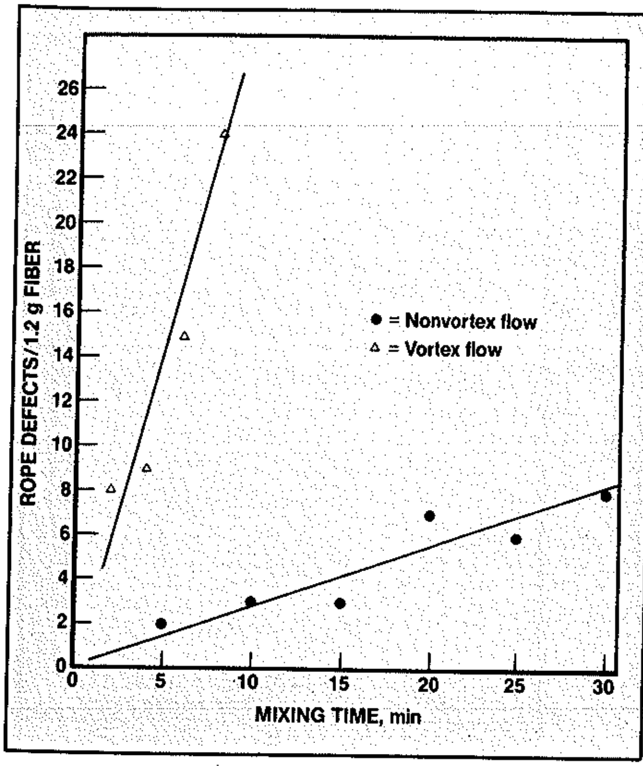
7. Effect of long-fiber concentration and overlength ratio on frequency of dumbbell defects in fabric. Overlength ratio = long-fiber length/nominal length. Nominal fiber length = 9.5 mm (3/8 in.)



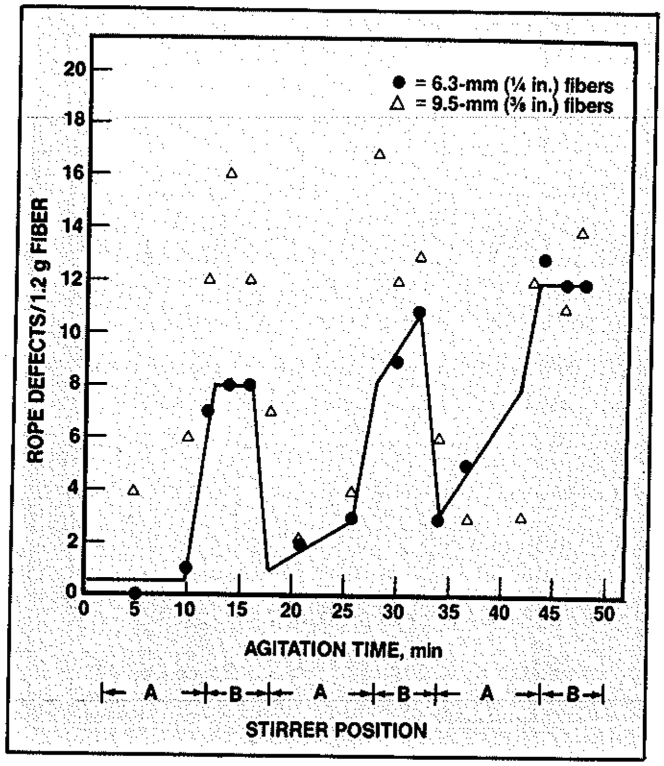
8. Effect of overlength ratio on frequency of dumbbell defects at constant long-fiber concentration. Nominal fiber length = 9.5 mm (3/8 in.); long-fiber concentration = 100/100 g fiber



9. Effect of mixing flow on rope formation. Nominal fiber length = 6.3 mm (0.25 in.)



10. Effect of agitation sequence on rope formation. A = no vortex; B = vortex



We conducted a test to determine (a) how long a fiber had to be to cause a dumbbell defect and (b) the fraction of overlengths that end up as dumbbells. Samples of 9.5-mm (3/8 in.) cut Dacron®T-257W were salted with known quantities of long fibers ranging in length from 19 mm (0.75 in.) to 57.2 mm (2.25 in.). The samples were processed into 40-g/m² nonwoven fabrics containing 60% polyester and 40% wood pulp. The polyester was dispersed with the pulp for 5 min in a pulper and then formed at 20 m/min (66 ft/min) on a 0.5-m-wide inclined-wire fourdrinier. Dumbbell defects in the fabric were counted, and the number of fabric defects per 100 g of synthetic were computed.

Figure 7 shows that the number of dumbbell defects observed in the fabric was a function of both the concentration and the overlength ratio of the excessively long fibers. (Overlength ratio = long-fiber length/nominal length.) Approximately 10% of the longer overlength fibers (44.4 mm) were converted to dumbbells no matter what the absolute concentration level. The number of dumbbells observed with the shorter overlength fibers (25.4 mm) was nearly independent of long-fiber concentration. Apparently, 25.4-mm overlengths did not form dumbbells in this particular machine.

Figure 8 shows that, at a constant concentration of fibers, the frequency of dumbbell formation was linearly related to overlength ratio. Overlength ratios of about 2-3 were required to have any significant impact on fabric defect frequency. In fact, fibers with small overlength ratios probably have no effect on fabric quality other than an imperceptible decrease in overall uniformity.

These results indicate that

- Fiber suppliers should strive to eliminate excessively long fibers
- Fabric producers should evaluate their fiber supply based on the presence of fibers with overlength ratios greater than 2 or 3. Fibers with overlength ratios less than this are probably not a factor in product quality.

Ironically, as fabric producers improve dispersion rates, fabric sensitivity increases. Improved dispersion splits the long-fiber agglomerates, which once acted as large-diameter fibers, into many single units. This effectively increases the concentration of long fibers and, thus, the formation of dumbbells. Therefore, if dispersion is improved at constant long-fiber level, fabric quality will deteriorate unless the wet-lay equipment is improved or the number of excessively long fibers is reduced.

Dumbbells can be minimized by using a fiber supply with a low long-fiber content and then running the furnish through snag-free approach piping.

Ropes

Ropes form when fibers encounter a vortex that is about the size of the fiber. Under such conditions, fibers are twisted into a string or, in extreme cases, they form agglomerates resembling the strands on a rag mop. Thus fiber supply, which plays an important role in the formation of log and dumbbell defects, is not a factor in rope formation.

To study rope formation, a laboratory stirrer (cloverleaf blade, 21-mm long by 17-mm wide, 45° pitch) was placed in 6 L of water contained in a 213-mm-diam. round glass container to which 1.2 g of polyester fiber (consistency 0.02%) was added. The stirrer was positioned 25.4

mm from the bottom of the container. Two stirrer positions were used. In position B, the stirrer was centered in the container and provided a fairly violent vortex. In position A, the stirrer was positioned 56 mm from the wall, and a 25.4-mm flat baffle was added at the wall opposite the stirrer to provide a relatively vortex-free rolling agitation. Agitator speed was accurately controlled at 800 rpm.

The procedure used was to agitate the fiber for a given time, stop the agitator, count the ropes, and resume stirring. Ropes were defined as assemblages of fiber discernibly more agglomerated than the average dispersion. This determination was somewhat subjective.

As expected, vortex flow had a powerful effect on rope formation. **Figure 9** shows that the rope-formation rate for the 6.3-mm (0.25 in.) fibers was approximately 10 times higher in the vortex flow than in the rolling flow. In this small-scale equipment, some vortexing occurred even with rolling agitation. Rope formation probably does not occur on a large scale during dispersion in large commercial agitators. It is most likely that ropes are caused by vortices in the approach piping, since these vortices are on the same scale as the fiber length. Limited experience on a 0.9-m pilot paper machine tends to confirm this hypothesis.

Surprisingly, many of the ropes formed in the vortex proved to be redispersible when the vortex was removed. This effect was discovered by stirring the fibers with alternately nonvortexing and vortexing flow. The results of this experiment are given in **Fig. 10**. This effect was true for both the 6.3-mm (0.25 in.) and 9.5-mm (3/8 in.) fibers. The effects of roping were more pronounced for the longer fibers, which confirms the common observation that longer fibers are more prone to roping.

Many of the ropes formed during initial dispersion will redisperse in devices such as the fan pump. These ropes will not re-form if the approach piping is free of vortices on the scale of the fiber length. Thus vortex elimination, or damping in the approach piping, is a key factor in minimizing roping. Vortices are typically caused by:

- Orifice plates used to measure flow rates
- Butterfly valves
- Gate valves or knife valves used for metering
- Dead-end tees in the piping
- Sharp elbows
- Instrumentation probes
- Abrupt reductions in pipe diameter
- Improperly designed pumps
- Improperly designed agitators.

Rope formation can be reduced through careful elimination of vortices. Viscosity boosters, which damp the violence of vortices, are also effective in reducing rope formation.

Improvements in dispersion rate also may increase the occurrence of rope defects, just as they do in the case of dumbbell formation. As dispersion improves, the fibers are present in more finely divided and thus lower-modulus form, which makes them more easily twisted.

Summary

There are three classes of defects in wet-lay nonwoven fabrics containing flexible organic synthetic fibers: logs, dumbbells, and ropes.

Logs are caused by either improper fiber supply or under-agitation. The specific cause can be identified by either determining log dispersion rate, examining the defects for fusing, or demonstrating that a longer dispersion time or a higher mixer shear rate can remove them.

Dumbbells are caused by snags in the approach piping. These snags capture fibers that are at least 2 to 3 times the nominal fiber length. Dumbbells can be eliminated by both improving the fiber supply and eliminating snags in the equipment.

Ropes are caused by equipment vortices that are approximately as long as the fiber. Elimination of ropes requires vortex removal or vortex reduction with a viscosity builder.

Increases in the dispersion rates of synthetic organic fibers allow fabric producers to use longer fibers while increasing the fiber content and uniformity of a wet-lay sheet. However, as dispersion rates increase, the potential for rope and dumbbell formation also increases. Teamwork between the fiber supplier and the fabric producer is essential.

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