

CHEMICAL AND MECHANICAL DAMAGE TO FELTS: A REVIEW

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ABSTRACT

Observation of hundreds of felt samples as a part of routine field technical support has led to formulation of general principles describing the results of chemical and mechanical felt wear. In addition, a series of experiments has been run exposing untreated Nylon-66 felt samples to the individual chemical components of multi-component felt-cleaning systems at typical machine concentrations temperatures and durations. These experimental exposures produce similar types of damage to that seen in field samples, but at far less severe levels.

It appears that nylon fibers consist of two phases much like epoxy-fiber composites, both phases of essentially the same composition. One phase appears disorganized, the binder. The other is organized as parallel groups of nylon molecules, the "sub-fibers." These are exposed by chemical attack during use.

The preliminary conclusion is that chemical damage largely results from chlorine attack, with an unknown but likely important influence of the mechanical stress of fiber flexing. These combined effects produce an extreme change in fiber condition, manifested as solution of the less-regularly organized parts of the fibers, leaving behind "unbound" fibrils parallel to the fiber axis. These are evidently somewhat embrittled, leading to fracturing, shredding of fiber ends and major loss of batt fibers.

INTRODUCTION

Paper-machine felts are an extraordinarily expensive "consumable" part of paper manufacturing. They are almost entirely made of Nylon-66 fibers. They usually consist of a base support fabric of coarser fibers which is then sandwiched between two more or less thick layers of batt fibers, so-called because they are originally formed up in a "batt" blanket of unwoven fibers, attached to both sides of the support fabric by "needling." Needling is a process whereby the base fabric and the batt are run together through an array of thousands of steel needles which literally poke the batt fibers in among the support fibers, or not infrequently right through the individual support fibers. The result is a high-porosity/high permeability, quite durable continuous blanket through which water can be removed from the drying sheet of paper.

Of course a major problem is that with suction applied to the sheet to pull the water out, other constituents also come out, including both paper fibers and other additives (filler, alum, etc.) All of these may get trapped in the felt and lower its permeability and decrease its capacity to function effectively. Chemical companies provide proprietary treatments to wash out these unwanted "foulants" with either batch or continuous felt washing systems.

Felt replacement usually has to take place every thirty to forty days.. Sometimes the felts are too heavily fouled and no longer absorb water satisfactorily. This condition appears to be relatively rare. The original porosity is decreased. The batt is usually more or less gone. What has happened to it? What about the support fibers? What is their condition?

No one appears to know whether failure is predominantly a mechanical or chemical phenomenon. There is a clear leaning among those who have to use felts to consider chlorine a "bad actor," in some way deleterious, but there are no published studies to document this prejudice. Almost no information is available on these questions in the published literature. No useful references to chemical damage to nylon fibers are available, even from the manufacturers of the fibers.

Felt design apparently has to do with the mechanical response of the weave to the machine and use conditions more than it does to local chemistry. That is, the high-speed movement of the felt through roll nips, the unsupported spans, the relatively high temperatures of the machine environment, these are the physical conditions to which felt

designers are apparently responding. It does not appear as though they are concentrating on resistance to the chemical environment, relying instead on the inherent stability of the almost-ubiquitous Nylon-66 fibers.

Some five years ago we began receiving used felt samples from the field with questions as to the relative severity of chemical and mechanical damage. We began archiving typical photographs of the felt fouling and fiber conditions. This paper presents a survey of those archives to acquaint readers with the range of “failure conditions” found in “normal” machine operations.

More recently an experiment was designed to isolate all the components of the chemical cleaning materials and examine their individual impacts on typical felt fibers under conditions of typical use temperature and concentration. The two major components missing from these experiments were, at first, chlorine and mechanical stress. The first of these has been remedied in part, although retaining chlorine concentrations in a stirred beaker is virtually impossible. The attempt is being made by replenishing the solutions every 24 hours. Experiments have all lasted for four weeks, nearly a typical felt life on the machine.

The first sets of experiments included typical individual pure components of felt-cleaning products, both alkaline and acid. When these were seen to have very little surface effect, the experiments were altered to include a 1ppm concentration of Cl- as bleach (sodium hypochlorite). Since this is a fugitive constituent in an open system, the entire liquid charge of the experiment was simply replaced fresh every day to replenish the Cl concentration. These experiments are on-on-going.

SAMPLE PREPARATION

The samples shown are either as-received from the field or from the experimental series. The field samples were simply dried or in one case, fixed in gluteraldehyde to preserve the structure of bacteria on the fiber surfaces. Pieces approximately 0.5 x 1 inch were cut from the felts with a fresh scalpel blade to create cross sections for viewing in the scanning electron microscope. These were plasma-coated with Au-Pd to make them conductive in the electron beam (although this is an imperfect coating process).

The experimental series was run by immersing 3 x 3 inch squares of fresh felt in stirred beakers of 200ppm solutions at 120 degrees F of the following materials:

ACIDS	OTHERS
Control – deionized water, pH 6.5	Control – deionized water, pH 6.5
Sulfuric acid, pH 2.35	50% NaOH, pH 10.36
Citric acid, pH 2.90	HEDP, pH 3.46
Phosphoric acid, pH 2.39	Alkyl phosphate ester, pH 4.51
Sulfamic acid, pH 2.55	Triethanolamine, pH 8.60
Sulfonic acid, pH 2.86	AMP (organic phosphate), pH 3.48

The felts are made of raw Nylon-66, grade 580, untreated.

DISCUSSION OF ILLUSTRATIONS

Figure 1 is a set of three cross-sections of felts at different stages of their progress toward failure. At the upper left is a fresh new felt, in the middle one illustrating some compression and batt loss, at the bottom right one having almost entirely lost its top and bottom batt layers. This succession of stages will be followed below in more detail.

Figure 2 is a repeat of the upper left corner of Figure 1, showing a fresh felt in detail. Note the open structure of the batts, with abundant interfiber porosity. Note the three sections: upper and lower batts and support fabric in the center, with much coarser fibers. Note that there is a twisted yarn running perpendicular to the coarse fibers. This is one of many variants on the structure of the support fabric, designed to optimize various mechanical features such as resistance to stretching or fouling.

Figures 3 and 4 show obvious needling damage in the support fibers, where needles have gone right through the center of the larger fiber, pulling batt fibers with it. This is inevitable, given the manufacturing process.

Figure 5 shows a used felt cross-section, with a great deal of flattening and compression of the batt. Fibers have become aligned by the pressure of the rolls, greatly reducing interfiber pore space. This batt compression is a major reason for loss of felt efficacy. In addition the residual pore space is further filled by contaminants, shown in Figure 6. Here debris is filling both interfiber spaces on the right and the void in the center of a crushed support fiber.

Figure 7 shows a somewhat higher magnification image of the central part of a felt containing multifilament yarn. The interfilament pores are largely filled with debris, also present as a major mass on the right. Here that debris can just be made out as containing many fine paper fibers as well as filler.

Figure 8 shows the center of a heavily-fouled felt with abundant granular filler debris. Commonly large pores will be partly filled by what appears to be a “cast” of the pore space. This is caused by the shrinkage of the foulant debris, which often exists as an aluminum-hydroxide-rich gel. When the sample is dried for examination in the SEM, the deposit shrinks, but retains the general shape of the pore space. These casts are commonly also loaded with paper fibers.

Figure 9 shows a fairly clean felt with a crushed support fiber and almost no top batt. The crushed fiber has at least four sub-segments now. Two less dramatic crushed fibers are also visible below the central one.

Figure 10 is a used felt cross-section with most of the batt gone. It is heavily fouled with PCC, precipitated calcium carbonate, shown in Figure 11. The size of the individual carbonate crystals is about 3 micrometers and smaller.

Figure 12 shows a felt cross-section with more batt than in Figure 10. However, heavy fouling is visible in the central support area. The spectrum in Figure 13 shows this foulant to be largely clay. Here a book of clay is seen, almost 4 micrometers thick, as shown in the center of the micrograph.

Figure 14 shows the surface of a virgin Nylon 66 felt fiber, never exposed to any chemicals, never on a machine. Note the faint lineation parallel to the axis of the fiber. This hints at the underlying structure of the fiber. Figure 15 shows a fiber which has undergone extended exposure to felt-cleaning chemicals. Note here how that lineation is now emphasized, deepened. It appears that the incipient development of the linear structure has been continued. What appears to have happened is that solution of a “continuous” phase has left behind a “discontinuous” phase. The discontinuous phase appears to be sub-fibers, parallel to the fiber axis. These must be composed of cylindrical bundles of long-chain molecules, whereas the continuous phase is the same or closely similar composition less well-organized. Note also in Figure 15 that the solution of the continuous phase has a limited axial extent, that is, the fiber is relatively deeply affected in the upper right part, but almost not at all in the lower left. It is suggested that this difference in response may have to do with the “working” or flexing of the fibers during mechanical deformation.

Figure 16 shows similar but much more extensive damage in a top view of a used felt. Note again the variability of the distribution of the damage to the various fibers. Note that these “sub-fibers” are all straight, parallel to the fiber axis. Figure 17 shows a fiber which has undergone two kinds of damage. At the upper right end, the central fiber has been flattened; it is no longer cylindrical. At the center and lower left, the fiber has “come unwound,” so to speak. It appears that the fiber has a spiral internal structure, not quite the same as that of those with parallel axial sub-fibers.

As damage becomes more severe, fibers begin to fail. There doesn't seem to be any reason for them to be under severe tension, so failure must be some combination of torsion and fatigue from flexure. Figure 18 shows a common view of surface batt fibers at this stage, viewed from above, while Figure 19 shows similar failed fibers deep within the structure of the felt. Note also in Figure 18 the severely-flattened fiber in the right center. In both these figures the broken fibers have a “shredded” appearance, much like a worn-out, broken manila rope. Figure 20 is an extreme, but typical, example of this shredding on a single batt fiber.

To revert to the experimental studies of acids and alkalis in contact with felt fibers, Figure 21 shows a fiber surface after three weeks of exposure at 120F to 200 ppm H₂SO₄ at a pH of about 2.4. Note the very slight lineation, much like that in Figure 22, a similar fiber exposed only to deionized water for 3 weeks at 120F, pH 6.6. Fibers exposed

to other pure acids and alkalis of various compositions had very similar appearances. There were two major differences between these experimental conditions and those on the paper machine: first, there was no mechanical stress to supplement the chemical stress, and second, there was no chlorine in the system. As mentioned in the description of sample preparation, this latter omission is being experimentally rectified at present, and results will be forthcoming.

Chlorine is usually added to the machine as part of a biocide program. To illustrate how important such control is, Figure 23 shows a complex array of foulant materials on a felt, including a paper fiber in the center and considerable granular filler. In addition, scattered through the debris are small cylindrical objects with rounded ends about 1 micrometer long. These are typical bacteria of unknown species. Figures 24 and 25 show these in greater detail and abundance. Clearly the biological control on this machine was failing to do its job. This was a "biofilm in progress." Slime was going to be a problem here shortly, if not already. The slime would be produced by the bacteria as "extracellular polysaccharides," a gelatinous mass produced to hold the colony or biofilm together.

Finally, to show that felts can actually survive and thrive under machine conditions, given the right treatment, Figure 26 shows a full cross-section of a felt after 33 days on a newsprint machine. Some of its batt is gone, but the fibers are in good shape and the interfiber pore space is clean.

SUMMARY

Felts operate in an environment of great chemical and mechanical stress. It appears at this point that the typical ingredients of felt-cleaning chemicals, by themselves, have little deleterious effect on the felt fibers. Experiments have not yet been completed to determine whether in combination they might have greater impact. The remaining stressors, as yet unchecked, are mechanical (the compression and flexing of the fibers during use) and the chemical impact of biocides.

It appears that the combination of chemical and mechanical stresses causes solution of a discontinuous phase in the fibers, leaving behind long (continuous?) fibrils, either parallel to the axis or spirally wound. These have sufficiently less strength than the virgin fibers that eventually they break, probably under the influence of the mechanical stress on the felt, causing loss of fibers. An additional major cause of loss of felt efficacy is loss of pore space because of alignment of fibers during compression of the batt. Not only do the fibers line up and compact, but the individual fibers actually are flattened by the compression.

Microcharacterization can be an important tool to help felt manufacturers, chemical and biocide suppliers and the mill operators minimize the impact of the machine environment on the felts and extend felt life.

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