flow sheet illustrating line flows, equipment motion and equipment arrangement.

FRANK W. LOREY, *Chairman*

Empire State (Western District)

The first meeting of the Western District for the 1961–62 season was held Oct. 4, 1961. It consisted of a plant tour of the U. S. Gypsum Co. at Oakfield, N. Y. (paper mill and board mill) and a dinner meeting at the Apple Grove Inn, Medina, N. Y. D. W. Daniel, personnel superintendent of U. S. Gypsum Co. spoke on "The Mining of Gypsum and Its 1008 Uses."

H. B. Hulse, chairman, Western District, Empire State Section

Since S. F. M. Maclaren, Penick & Ford, Ltd., has been transferred to their New York Office, R. Zimsmeiter is now Membership Committee chairman and L. B. Timmerman is Membership vice-chairman.

H. B. HULSE, *Chairman*

Gulf Coast

Experiences with Metal Failure Problems in the Pulp and Paper Industry

W. M. Stephenson, J. R. Nelson, and E. G. Johnson

The economic importance of recognizing and solving metal failure problems in the paper industry are considered. Basic types and causes of metal failures are discussed and illustrated. Analytical methods are reviewed and field corrosion measurements briefly considered. Special attention is focussed on the problem of fourdrinier wire life and the three factors which influence it. These were mechanical damage, abrasive wear, and corrosion. None of the three are independent. They must be considered together and solved as one complex problem. Methods available for doing this include personnel education, special attention to mill cleanliness, good operating procedures, and the application of specially designed chemical formulations to reduce wear, maintain drainage, and eliminate corrosion. The potential savings in wire replacement costs, lost production, down time, and labor costs are great enough to justify continued attention.

IT IS almost impossible to assess accurately the cost of metal failure to American industry. Many plants do not have anyone specifically assigned to the task of monitoring and reducing these problems, and data are sparse. A recent article in *Chemical Processing* magazine (*1*) assigned a figure of 6 billion dollars as the amount lost by all American industry in 1960 due to corrosion alone. No breakdown as to specific industries was given. When metal failures other than corrosion are considered and an attempt is made to include lost production and extra labor costs involved in the downtime to replace or repair metal that has failed, the total dollar loss would be staggering. Fifteen billion dollars might be a conservative estimate.

Pulp and papermaking operations are particularly susceptible to metal failure problems, since their nearly continuous operation makes it difficult to carry out good preventive maintenance programs. Water usage in each mill of 20 million gallons per day or more is common. Therefore, chemical protection of the vast amounts of metal in a papermaking system is hard to achieve. While we cannot assign a dollar value to the metal failure problems in the paper industry, we know the magnitude is great. Each member of this TAPPI group surely is aware of the significance of metal failure in his individual mill.

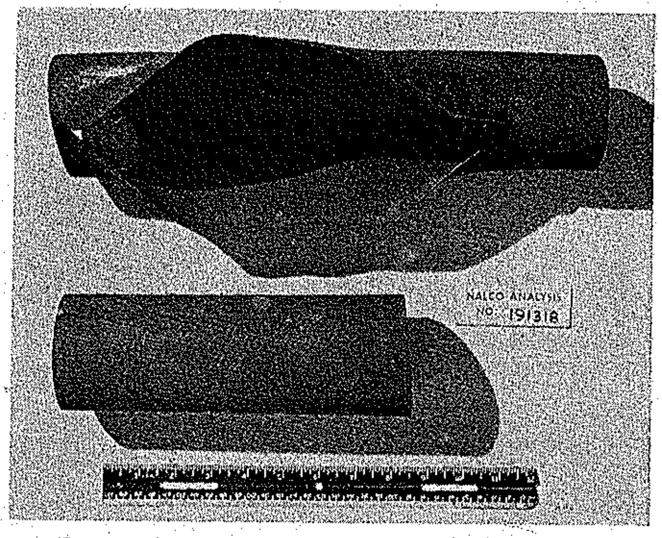

Fig. 1. Gross photograph of ruptured boiler tube

Metal failure problems can and do occur throughout the papermaking system—from the woodyard through the power plant and pulp mill to the paper machine and into the converting plants. This discussion will be centered around a very brief description of several general type failures which are common to the pulp and paper industry. It will be focussed primarily on a problem which has commanded a great deal of attention, the failure of fourdrinier wires. Brief descriptions of corrosion measurement techniques, analytical considerations, and metallographic examination procedures will be included.

REPRESENTATIVE TYPE METAL FAILURES

Overheating to various degrees is a very common metal failure problem which occurs in power boilers, recovery boilers, and steam generating units. A study of the metal structure at several points in the region of failure will usually yield information about the severity of the overheating. As some metals

Fig. 2. Martensitic Structure (500×)

W. M. STEPHENSON, J. R. NELSON, and E. G. JOHNSON, Nalco Chemical Co., Chicago 38, Ill.

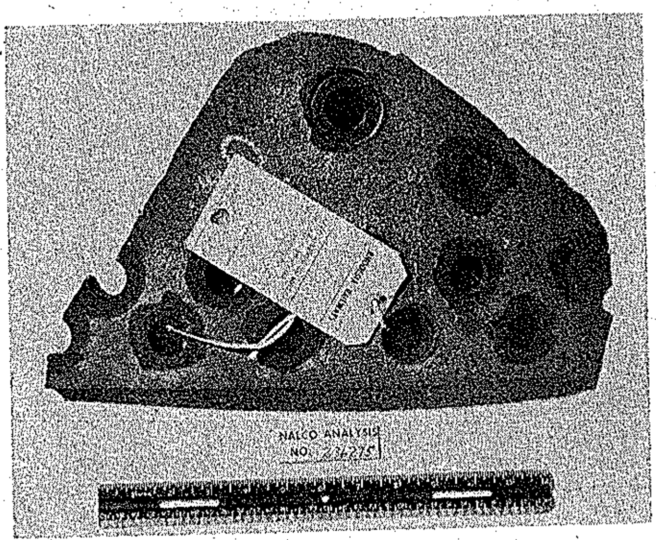

Fig. 3. Boiler plate—gross photograph

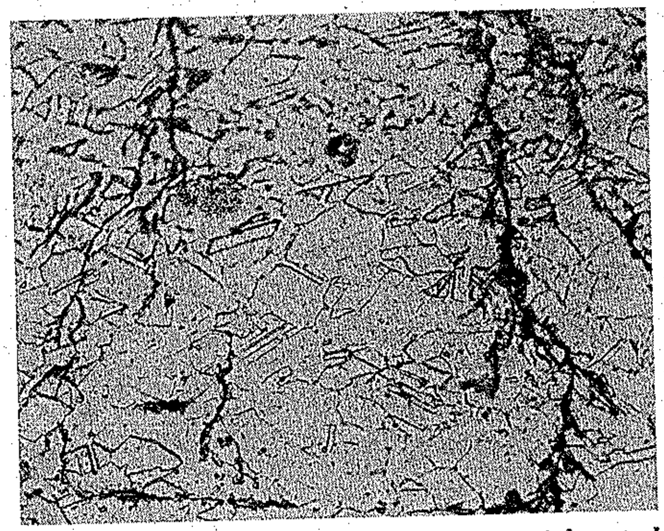

Fig. 5. Stress corrosion cracking in type 347 stainless steel (500×)

are heated, structural changes occur which depend on the temperature reached and time exposed. As an example of what can happen, Fig. 1 shows an overheated boiler tube which ruptured violently.

The temperature of this tube had exceeded the upper critical limit before rupture and drastic quenching occurred at the time of rupture through water and vapor issuing from the fracture as shown by the "martensitic" structure in this slide. Figure 2 was prepared from a photomicrograph taken at a magnification of 500×.

Failure of this type in a papermill powerhouse can easily shut down the mill until such time as repairs can be made.

A second type of failure which is often encountered in boilers and can easily occur in kraft digesters is caustic embrittlement. When metal is under stress, contact with a water or liquor containing caustic and small amounts of silica can cause embrittlement if a small leak allows concentration of alkaline solids on stressed surfaces. Figure 3 shows a boiler plate section which appeared sound to the naked eye. It was actually greatly weakened by embrittlement.

Metallographic examination revealed internal damage in the form of cracks in the metal structure. Figure 4 illustrates the type structure encountered in caustic embrittlement cracking. This photomicrograph was taken at an enlargement of 500×.

The use of corrosion-resistant alloys does not always guarantee freedom from metal failure problems. In work done on corrosion-resistant alloys to be used in sea water-cooled heat exchangers in nuclear power plant applications, excessive stress cracking was found in certain alloys. Figure 5 shows stress corrosion cracks originating at the stressed surface of a sample of type 347 stainless steel. The magnification here is 500×.

Erosion of metals can cause severe damage and put equipment out of operation in a short period of time. Figure 6 shows a stainless steel centrifugal pump impeller which has been badly damaged by erosion while pumping a filler clay slurry.

Microbiological attack can occur on nearly any metal surface in a pulp or paper mill where deposits collect or anaerobic conditions exist. Anaerobic bacteria caused the pitting type corrosion attack on the stainless steel coating color tank illustrated in Fig. 7 showing a piece of metal taken from the side wall of the tank. An adequate coating preservation program could have prevented this serious metal loss.

Chemical corrosion can destroy any pipeline or stock line in a mill system if allowed to proceed unchecked. Figure 8 shows a chemical line constructed of ferrous metal which was destroyed by straight chemical corrosion.

These examples constitute only a very brief sampling of the general types of metal damage going on in your mills every day. An awareness of the potential problems is required to be able to effectively combat the problems. Some of the problems can be easily recognized by anyone. More frequently the services of a trained metallurgist are required to ac-

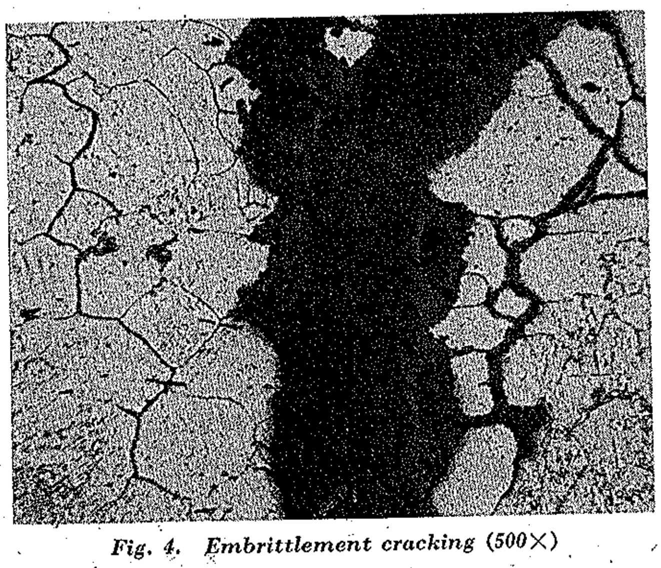

Fig. 4. Embrittlement cracking (500×)

Fig. 6. Eroded stainless steel pump impeller—gross photograph

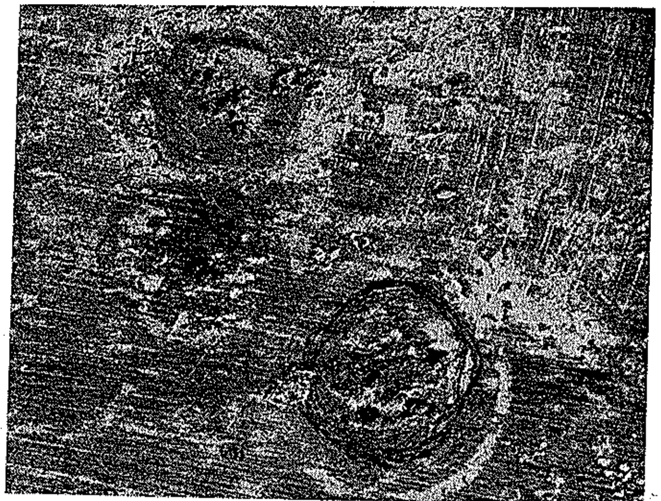

Fig. 7. Microbiological corrosion on stainless steel coating color tank—gross photograph

curately diagnose the factors involved and to translate the observations into improvements in operating results.

METALLOGRAPHIC ANALYSIS—A KEY TOOL IN EXAMINATIONS OF METAL FAILURES

All of the pictures shown, as well as those to be shown later, were prepared in our metallographic and photographic laboratories. In over 35 years of dealing with metal problems and the protection of metals, Nalco has gained a large amount of experience in examining failed metal, ascertaining the causes for the failures, and recommending solutions to the problems. The metallographic and associated analyses are key tools in doing this. A brief discussion of the procedures and techniques employed would be helpful at this point. Any combination of, or all of, the following steps may be included as necessary.

1. The first step in a metallographic examination is photographing the sample from various angles to record the exact appearance of the failure in the sample received. Then, trained metallurgists examine the sample to determine what steps should follow.

2. The sample is next examined under low and high magnification with a binocular microscope to get an accurate three dimensional view of the characteristics of the failure. If necessary, the sample can be sent to an independent laboratory equipped for Magnaflux and Magnaglo examination to accurately locate surface and internal imperfections or failures.

3. Then, several small samples will be cut, molded in plastic, ground, finished, and etched in order to examine and photograph the metal structure under high magnification through a special metallographic microscope. For extremely high magnifications and study of very minute characteristics of the metal, the electron microscope may be used.

4. Specimens of the normal metal may be subjected to dynamic testing in specially designed corrosion, abrasion, and embrittlement testing units to duplicate the problem and confirm analysis results.

5. If the sample is corroded, scaled, or contains a deposit of any kind, this will be removed and analyzed in the analytical laboratories using chemical, photometric, infrared, chromatographic, and x-ray techniques.

6. Samples of the process water, solution, suspension, slurry, or dispersion which contacted the metal during its service will be analyzed completely by standard chemical or instrumental analytical methods. When all of the data are collected and properly interpreted in light of operational information, a thorough understanding of the causes of the problem will be apparent. From an understanding of the problem, recommendations for solving it can be intelligently made.

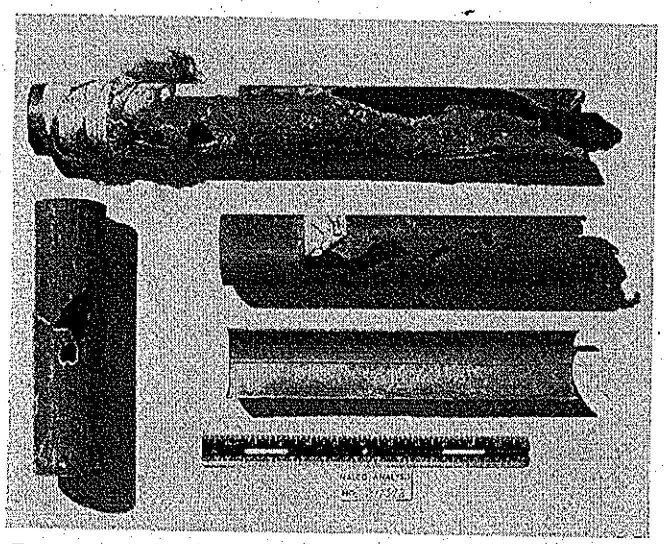

Fig. 8. Chemical corrosion of chemical line—gross photograph

CORROSION MEASUREMENTS IN THE FIELD

The nature of the pulping and papermaking operations makes corrosion of equipment one of the major metal failure problems in your industry. Many authors have defined the various types of corrosion and the factors which influence corrosion rates. For purposes of this discussion, it suffices to say that corrosion is accelerated by low pH, high temperature, high total acidity, high dissolved solids contents in process waters and white waters, corrosive dissolved solids and gases, vigorous aeration, and the repeated abrading off of protective films or corrosion products. Microbiological activity can also cause corrosion. All of these conditions for promoting corrosion exist in a paper mill and are estimated to cause losses of approximately 30 to 90 million dollars annually. Metallographic analytical techniques are extremely valuable in understanding and solving corrosion problems, but field methods to measure corrosion and monitor process changes and their effect of corrosion in operating equipment are frequently necessary. Available field methods were discussed by Nelson in an article appearing in the July 24, 1961, issue of *Paper Trade Journal* (*2*). Basically, these methods include inspection of the equipment during periods when it is not in operation, review of maintenance cost records, chemical analyses of process water, installation and use of corrosion coupons throughout the system, and direct measurement with electrical resistance probes. Equipment inspection is perhaps the best way of ascertaining the damage being done to the metal in question. However, it is frequently impossible to adequately inspect an operating unit, and damage may be hidden in inaccessible areas. Months or years may pass before damage is detected in this way and then it is too late to prevent it. Corrosion coupons provide a more rapid means of measurement, normally between 15 and 60 days. Coupon data are useful for comparing process changes, but are limited to "average" values and will not reflect rapid or frequent operational changes. Within the last ten years, electrical resistance probes have come into use to provide a rapid measurement of corrosion rates. Several probes can be installed throughout stock and white water systems and all measurements then made with one instrument without interrupting production. The order of magnitude of corrosion rates can be measured in a few days, or hours in some cases. The influences of changes in furnish, water, pulp washing, and stock preparation can be detected and measured as they occur. Immediate steps can then be taken to properly protect equipment before irreparable damage is done.

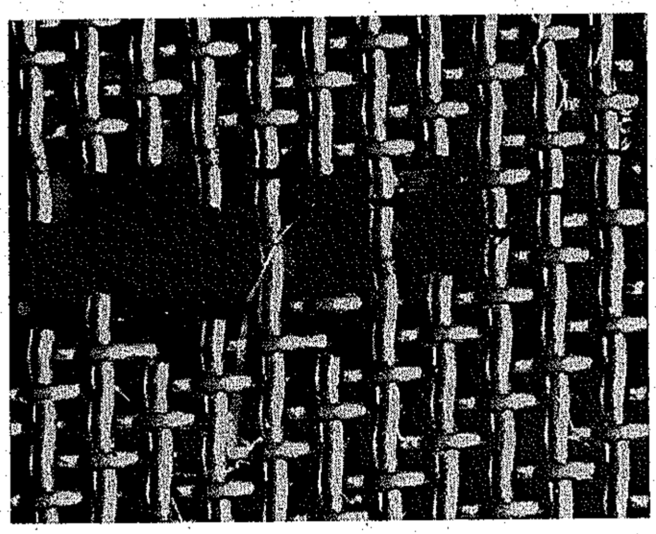

Fig. 9. Tear and cracked shute wires (12×)

METALLOGRAPHIC EXAMINATIONS AND FOURDRINIER WIRES

With many years of experience in metal failure problems, we have also investigated what is probably one of the major metal failure problems in the paper industry today—the problem of fourdrinier wire life. The economic situation which has existed over the last few years, a more acute awareness of operating costs, austerity programs, and the trend to bigger and faster paper machines have focussed attention on the large savings which can be realized by achieving the maximum life out of each fourdrinier wire installed. Samples we have received for metallographic analysis consistently show good quality in fourdrinier wires. In those examined, no evidences of faulty material or defective manufacture have been detected. This means that when a wire gives less than satisfactory life, the situation can usually be corrected within the paper mill.

ECONOMICS OF WIRE LIFE IMPROVEMENT

The Lindsay Wire Weaving Co. of Cleveland, Ohio has quoted wire costs as high as $2.80 per ton in some high speed newsprint mills and lists as an average for all newsprint mills a figure somewhere above $1.30 per ton (*3*). Data collected during the last six months on wire costs in the southern kraft industry indicate that $0.65 to $1.25 per ton are fairly typical values for mills in this area. An average annual increase of 50% in the life of fourdrinier wire will reduce costs by one-third, while doubling the wire life will cut the costs in half.

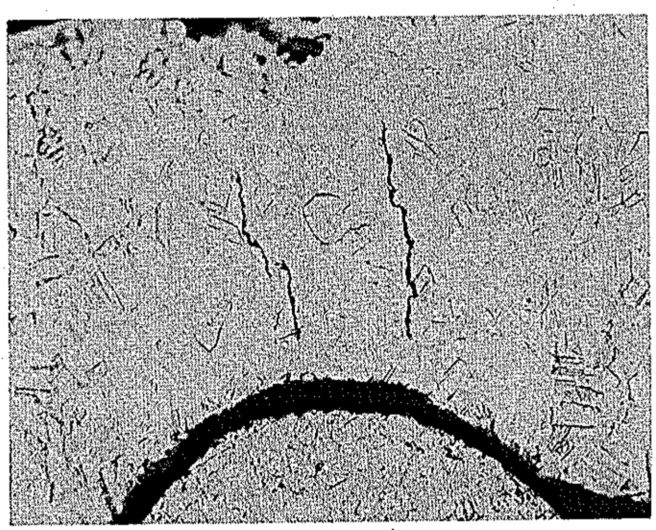

Fig. 10. Intergranular cracking in brass shute wire (500×)

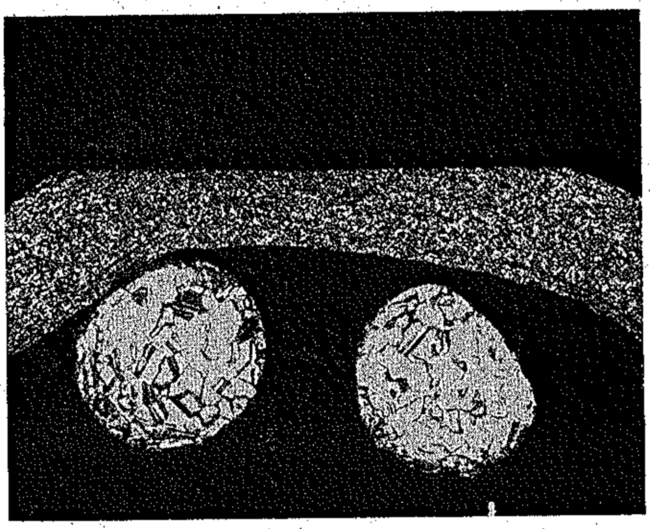

Fig. 11. Worn warp wire (250×)

This kind of cost savings is easily within the realm of possibility for those mills or machines where the average wire life is 15 days or less. In addition to the direct savings in wire replacement costs, the reduction in downtime for wire changes and the reduction of labor costs for the extra manpower involved in wire changes can make even relatively short wire life extensions quite attractive to the papermaker.

FACTORS IN REDUCED WIRE LIFE

Most fourdrinier wires are removed from service long before they have completed a normal tour of duty. One of the major causes for early removal is mechanical damage suffered during installation or operation on the machine.

1. Ridges, wrinkles, or creases can result from rough or careless handling during transit, storage, or installation. Dirt, grit, or stock on machine surfaces or stringing poles will cause dents, jams, or pimples in the wire during installation. Scrupulous cleanliness and thorough education of mill personnel in wire handling can eliminate this cause of damage.
2. Damage during operation frequently occurs as stock or other foreign material is forced between the wire and one of the outside rolls. This causes a dent or downward jam which will quickly wear into a hole. Plugged or filled wires can easily suffer this type damage due to inefficient stock removal. Material on overhead crane rails, the headbox, catwalks, or stairways near the wet-end can be blown or washed onto the wire causing dents or holes.
3. Upward dents or pimples result when hard stock or for-

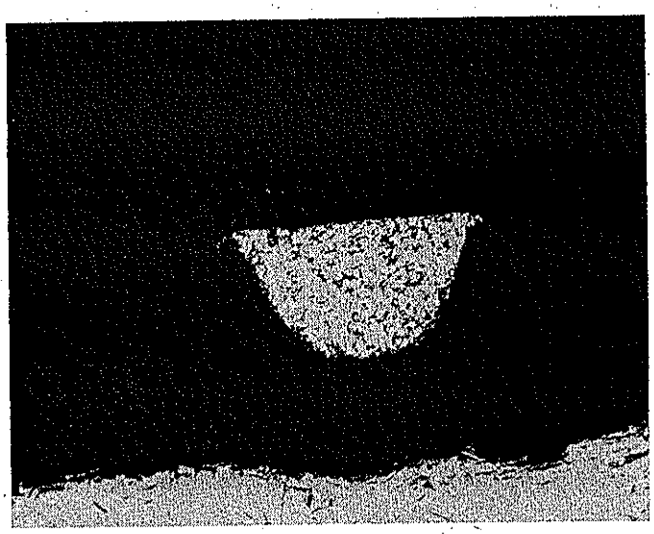

Fig. 12. Cross section worn warp wire (250×)

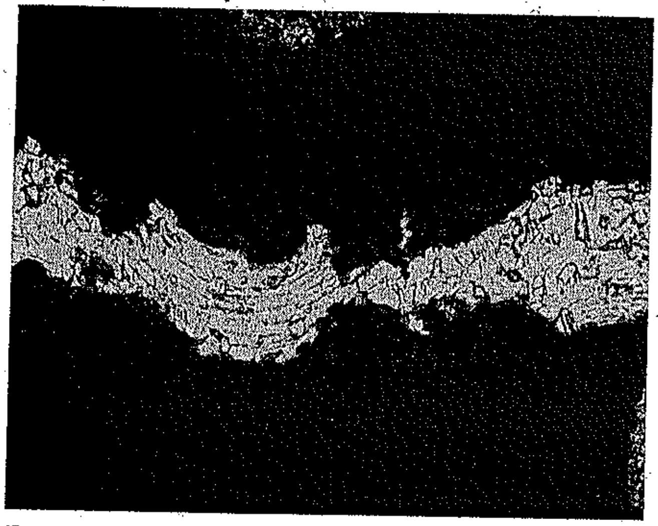

Fig. 13. Longitudinal section of badly corroded shute wire (250×)

eign material is forced between the wire and an inside roll. Such material can drop off the suction boxes, trays, shower pipes, or machine frame. These upward pimples cause light spots in the sheet and may in extreme cases hang on the slice and cause a tear.

4. Ridges, wrinkles, or creases which are responsible for many short wires can also result from misalignment of a roll which results in whipping or vibration, unbalance in a roll, improper tension in the wire, a vibrating deflector or a build up of pitch, slime, stock or foreign material on the flat boxes or deflectors. Some wires are wrinkled when cold fresh water replaces hot white water in the showers during a shutdown.

5. Sudden changes in flat box or couch vacuums, variations in the motor load on drive rolls, or previously undetected splits and holes can cause wires to tear off the machines. Flat box oscillators stopped or running in unison can cause the wire to hang on the boxes and tear. Failure of the automatic guide can allow the wire to run off. People or objects can fall or run into wires.

Figure 9 illustrates one type of damage just discussed. The tear in this wire occurred when a misalignment of some part of the machine caused the wire to whip. Intergranular cracking of the brass shute wires resulted.

Figure 10 illustrates the damage to the metal structure of the cracked shute wires just shown. Here, intergranular cracking which weakened the brass metal structure is evident. This photomicrograph was taken at 500×.

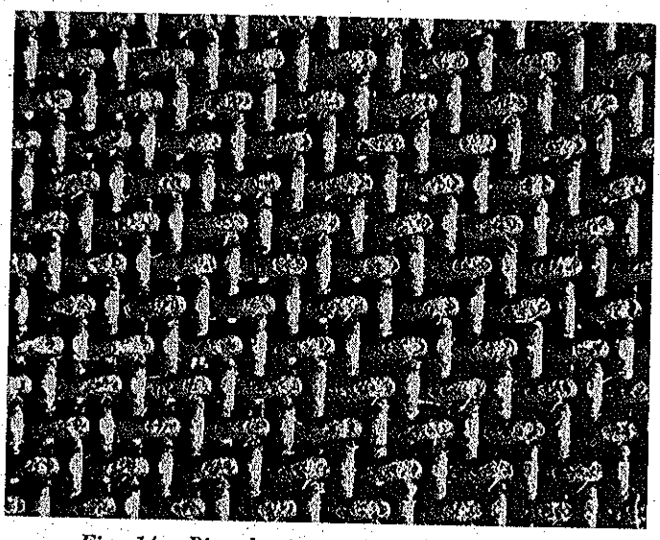

Fig. 14. Pitted wire—sulfide attack (12×)

Fig. 15. Transgranular cracking as a result of corrosion fatigue—shute wire (400×)

The primary reason for wire replacement is wear. The type of alloys used in the wire, the mesh, temperature, pH, chemical additives, fillers, grade of paper produced, and general machine condition all influence wear on the wire.

1. Abrasive wear occurs on the suction boxes, deflectors, forming board, deckles, and on the couch roll.

2. Sand or grit in the white water, the use of abrasive fillers, and high temperatures which lower the viscosity of the water will accentuate the wear rate.

3. Filling of the wire by stock or furnish chemical deposits, pitch or corrosion products, and the reduction in open area caused by wear necessitate higher flat box vacuums to remove water from the sheet. This increases the wear at the boxes.

4. Poor machine design or poor maintenance often contribute to wear. Running the wire around sharp radii can cause wear hardening and fatigue failure.

5. Allowing the wire to run over dirty or grooved suction box covers or faulty setting of the slice and deckles will greatly increase wear.

Figure 11 shows a longitudinal view of a worn warp wire at an enlargement of 250×. Note the semitwill weave of this particular wire.

Figure 12 illustrates the wear on a warp wire in a transverse view at an enlargement of 250×. Note the burring which reduces the open area of the wire and slows its effective drainage.

The third classification of factors which influence wire life is corrosion. Authorities differ considerably in their opinions

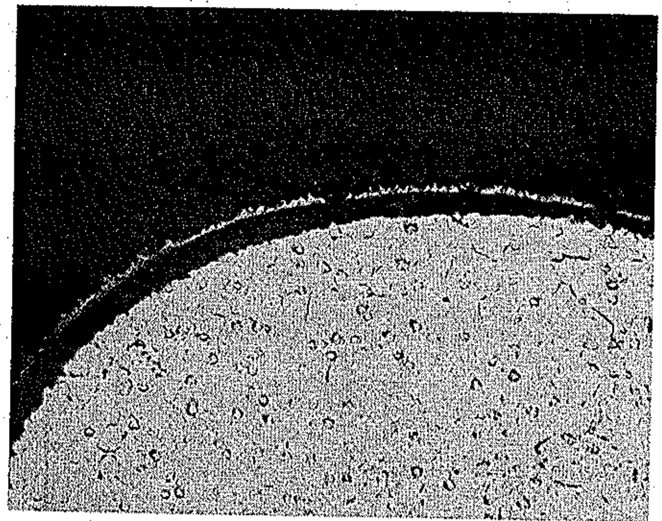

Fig. 16. Warp wire cross section showing layer of corrosion products (500×)

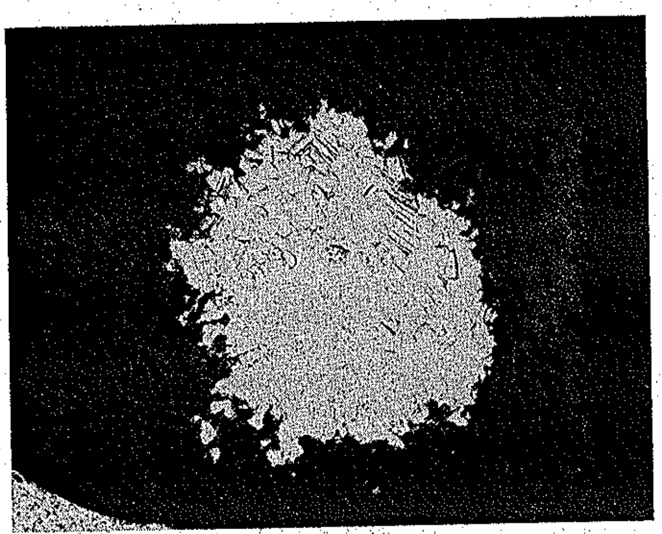

Fig. 17. Corroded shute wire—cross section (250×)

concerning the severity of corrosion problems in reducing wire life. Some mills are constantly troubled with corrosion, others have unrecognized problems, and still others may operate for long periods of time without encountering it. When it does occur, it can drastically shorten wire life. In this discussion, consider that wire life is influenced by a combination of damage, wear, and corrosion factors and where corrosive conditions do exist that they contribute considerably to increased wear rates. Most white waters are acid, contain high concentrations of dissolved solids, and are vigorously aerated in the papermaking process. Materials used in the furnish may increase corrosiveness. They may enter the system from the pulp mill or may be present in the process or raw water. High temperatures are frequently added to the above conditions to produce white water with an aggressive corrosion potential. The types of corrosion encountered in fourdrinier wires is similar in nature to that found in tanks, pipelines, white water lines, stock lines, boilers, cooling towers, etc. Metallographic analysis will show the exact nature of the corrosion and its relationship to the wear and damage factors involved. Even though the brass and bronze alloys normally used for the shute and warp wires respectively are quite similar, their resistance to corrosive attack is quite different. The brass shute is generally more susceptible than the bronze warp and provides some anodic protection to the warp.

Figure 13 shows a very badly corroded shute wire at a magnification of 250×. The warp wires from this particular sample were almost free from attack even though the machine operated at a high temperature and at very low pH's.

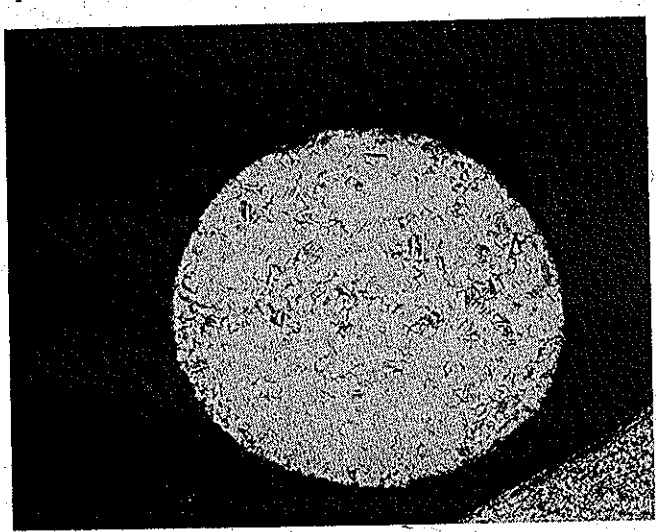

Fig. 18. Protected shute wire—cross section (250×)

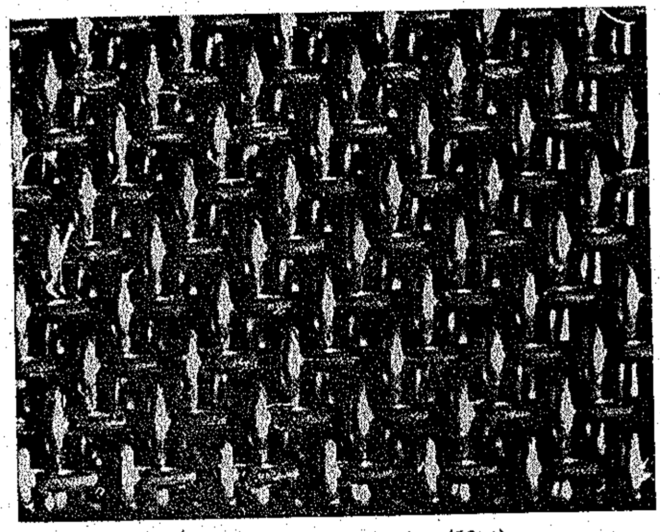

Fig. 19. Protected wire (12×)

A pitting-type attack is frequently noted under sulfide deposits. This type attack is especially prominent in areas where the hydrogen sulfide content of the fresh water is high. Even when the sulfides in fresh water are oxidized with chlorine, typical sulfide pitting attack is frequently observed.

Figure 14 shows a section of wire at a magnification of 12× in which the brass shute knuckles are severely pitted. X-ray analysis of the deposit covering the wire showed it to be primarily copper sulfide. The fresh water supply at this particular mill is high in hydrogen sulfide content.

Transgranular cracking is often associated with corrosion and fatigue. As flexing and fatigue break down surface films of corrosion products, deep penetration, and concentrated local attack is likely. Corrosion and fatigue also play important parts in increasing the wear rate on the warp wires. When the relatively soft corrosion products are flexed or abraded off, a clean fresh surface is exposed which can corrode rapidly. Alternate corrosion and abrasion in this manner can accelerate wear rates and shorten wire life.

Figure 15 demonstrates transgranular cracking of a shute wire which resulted from alternate corrosion and fatigue. This photomicrograph was taken at a magnification of 400×.

Figure 16 illustrates at a magnification of 500× one of the few samples in which warp corrosion has been definitely identified. Please note the adherent layer of corrosion products on the surface of the warp wire. It is this layer which easily abrades off and increases the rapidity of warp wear.

INCREASING FOURDRINIER WIRE LIFE THROUGH PROTECTION

To repeat, wire life is influenced by *damage*, *wear*, and *corrosion factors*. The first step in increasing wire life is reducing damage. Careful attention to handling and operating procedures and scrupulous cleanliness on and around the machine will minimize damage to the wire. Good slime control and pitch control programs will reduce build-ups of foreign material on the machine and further reduce damage factors. Wear and damage can both be reduced by a thorough program of preventive maintenance. Careful screening of stock and the use of less abrasive fillers will reduce abrasive wear on the suction boxes. Prevention of wire plugging or filling will maintain effective drainage on the wire and eliminate the need to increase vacuums on the flat boxes. Protection against corrosion can be obtained by increasing operating pH's and reducing dissolved solids in the white water to levels which will reduce the corrosiveness of the white water and still be consistent with good papermaking practices. Improved pulp washing, efficient water treatment, and careful selection of furnish chemicals contribute to a reduction in corrosion. The high temperatures and vigorous aeration encountered in most machine systems can only rarely be avoided.

CHEMICAL FORMULATIONS TO INCREASE FOURDRINIER WIRE LIFE

In the last few months, several chemical formulations to improve wire life have been offered to the paper industry. Dramatic wire life extensions of 50 to 100% have been demonstrated. These chemicals can be used most efficiently to supplement good operating practices as previously discussed. To do a really effective job, a wire life extender should be formulated of several compatible ingredients to perform at least three functions:

1. The chemical should film the wire to prevent pitch, fines, chemicals, and other deposits from adhering tightly. The wire showers can then clean the wire more efficiently and effective drainage can be maintained. A slight amount of dispersancy aids in this function.
2. The extender should also lightly lubricate the wire to reduce abrasive wear, but not produce slip on the couch and drive rolls.
3. The third important function of a wire life extender is to eliminate corrosion on the wire.

In order to perform these important jobs, a formulation containing several ingredients is necessary. However, the formulation should be considered and applied as a *wire life extending chemical* rather than as an ingredient in another operational chemical to be applied in some other part of the system. This is because the problem is centered at the machine where direct attention is necessary.

The next series of figures illustrate what has been observed in metallographic examinations of failed wires, without and then with wire life extending formulations. Figure 17 shows a badly corroded shute wire cross section at a magnification of 250×.

Figure 18 shows a shute wire from the same paper machine when a wire life extender was being used. This wire ran under the same operating conditions as the wire just shown, but was protected with a wire life extending chemical. This second wire ran approximately 75% longer than the first one.

Figure 19 shows a view at 12× of the wire from which the protected shute was taken. Even though the mill involved had a history of short wire life due to wear and corrosion, this wire which was protected with a wire life extender shows absolutely no corrosion and had less wear than normal wires even after running 75% longer. The wire was ultimately removed because of mechanical damage, a hole caused by a pimple in the wire, and not because it was worn out.

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Presented at a meeting of the Gulf Coast Section of TAPPI.

The magnifications specified on the photographic enlargements are those of the original 9 by 11 cm. photomicrographs. The actual magnification in these photographs is less than indicated.