Durability of Geotextiles in Railway Rehabilitation

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The durability of geotextiles installed in railway rehabilitation applications is investigated by examining the track conditions and the change in properties of exhumed geotextiles at different time intervals. Properties examined include soil fouling content, change in permeability ratio, and change in geotextile strength. These properties are related, as appropriate, to characteristics such as filtration opening size. The results are discussed in terms of the geotextile's primary functions of filtration, drainage, separation, abrasion resistance, and elongation. Data collected before 1982 were used to develop a track rehabilitation geotextile specification for use without a capping sand. Data collected after 1982 were used to support and confirm the validity of the specification. This specification was adopted and has been in use in the Canadian National Railways Maritime Region since 1981. It has also been used for rehabilitation of other railway company tracks. Correctly installed geotextiles meeting the specification have given satisfactory performance and have been cost-effective.

Geotextiles were introduced into North American railway tracks in the 1970s to correct some of the problems related to track support. Similar problems were being addressed on European, Japanese, and other railways that are subject to lighter axle loads. Most of the problems were related to inadequate internal track drainage, whether because of the topography or because of created drainage problems. In North America these problems were, and still are, aggravated by the use of heavier freight cars and greater freight quantities. This results in more frequent repetitive loading by larger loads, which have also increased since the original designs.

Initially the technical recommendations for selecting track geotextiles were adapted from applications that were not railway-proven. Experience soon indicated that the North American track environment is much more abrasive and demanding on geotextiles than originally thought. Consequently, a project was funded in 1980 by Canadian National Rail, Canadian Pacific, and Transport Canada through the Canadian Institute for Guided Ground Transport with Queen's University. The objective was to develop guidelines for use of geotextiles in North American railway track rehabilitation applications.

A literature review was conducted and North American railways were assessed on their use of geotextiles for track rehabilitation. Visits were then made to a number of Canadian sites and excavation were made to exhume geotextiles (*1*,p.153). The author also visited two U.S. locations (2,p.35) as a guest of the Consolidated Rail Corporation (Conrail).

After development of the specification, excavations were made to confirm its validity. In addition excavations were made at other sites where geotextiles were installed. These results all added support to the findings of the prespecification study.

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PRELIMINARY ASSESSMENT ON CANADIAN TRACKS

The first task undertaken was to obtain details of geotextiles installed on Canadian railways. Preliminary assessments were then made to record the surficial conditions at some selected sites. Selection was based on type of geotextile, ease of accessibility, geographical location, and the like. Sixteen sites were visited in June and July of 1981. A geotextile had been installed at all sites within the previous (to 1981) 5 years. Visual examination of the track adjacent to that containing the geotextile demonstrated that there were poor drainage conditions at all sites. All were located in areas susceptible to pumping fines from either fouled ballast (fouled from any one of a number possibilities) left at the track undercut interface, subballast with excess fines, or the subgrade. The most obvious observation made was that the installations were at areas that were hard to maintain and drain, including grade crossings and track switches. The fact that a geotextile was used was indicative that a ballast support stability problem had been identified.

Fifty percent of the sites exhibited reasonably stable track structure conditions. These had all been rehabilitated with a nonwoven geotextile of mass/unit area of 500 g/m^2 or greater.

The balance of the sites all exhibited at least some surficial pumped fines at the track surface. As noted, all were in areas of poor drainage; however, this was also true of all the sites in reasonable condition. At some of the sites in poor condition, the ballast was close to being completely fouled, despite having been rehabilitated within the previous 5 years. Some of these poorly performing sites exhibited varying degrees of tie movement or wear, track out of gage, and some already required track upgrading. All these poorly performing sites had been rehabilitated with nonwoven geotextiles of mass/unit area of 400 g/m^2 or less.

From the information gathered on site installation location and from the 16 sites visited, conclusions were formulated relating to theoretical considerations for geotextile selection. These are given later.

ASSESSMENT OF CANADIAN 500 g/m^2 GEOTEXTILES

Six Canadian sites having had geotextiles installed before the start of this study were selected from those exhibiting reasonably stable track structure conditions for further site investigation. All had been rehabilitated earlier with the heaviest mass/unit area geotextile in use on Canadian National and Canadian Pacific railways before 1981. At these six sites excavations were made during the summer of 1981 to exhume a sample of the previously installed geotextile. The exhuming consisted of pulling one tie and excavating the distance of one tie width and two crib widths. Great care was taken not to damage the geotextile during excavation and removal. In all cases the excavations were continued to the subgrade, and in all cases the subgrade was protected by an intake filter subballast layer that was found below a fouled ballast layer. No evidence was found of fines migrating from the subgrade. In most cases the migrating (pumping) fines through the geotextile consisted of degradated ballast fines migrating from the fouled ballast surface left after undercutting.

The universal problem noted at all sites was a partial lack of drainage considerations during installation. In many instances the geotextiles were installed so that they were unable to drain moisture to the shoulders and then into the side ditches. Preventing bathtub and canal effects at all rehabilitation sites, whether with or without a geotextile, is now considered of paramount importance.

One factor contributing to a geotextile's performance was the depth at which the geotextile was installed below the base of the ties, because abrasive action increases as the geotextile is placed closer to the base of the tie. Even minor worn-through areas (i.e., holes), in the presence of water, will permit migration of fines that damage the ballast. Thus any damage reduces dramatically the function of the geotextile, as clearly demonstrated by the sites visited. The percentage of measured, completely worn-through areas (i.e., holes) of the worst 300 mm × 300 mm of each exhumed geotextile was plotted against exhumed depth below the tie base. The values range from 0.3 percent at a depth of 350 mm to 4.1 percent at a depth of 175 mm. The damage increased rapidly when the exhumed depth was less than 200 to 250 mm.

ASSESSMENT AT LOUDONVILLE ON CONRAIL TRACK

Five visits were made at 6-month intervals to a geotextile test site at Loudonville, Ohio, as a guest of Conrail. At this site eight different types of geotextiles were installed, all with a mass/unit area less than 500 g/m^2. During the first site visit the geotextiles were at a depth 200 mm below the base of the ties. These included woven and thin heat-bonded as well as needle-punched nonwoven geotextiles. Again the fouling fines were degraded ballast fines from the ballast adjoining and below the undercut surface.

The condition of the exhumed geotextiles after 2.5 years is shown in Figure 1. Clearly the condition of the geotextiles shown in Figure 1 confirms the findings made from the Canadian sites (i.e., if a nonwoven geotextile were to be used it would need to have a mass/unit area of at least 500 g/m^2).

In addition the results at Loudonville indicated that the woven and thin heat-bonded geotextiles plugged and acted as plastic sheets, leaving the underlying surface coated with a thin layer of wet plastic slime of moist fines. These observations were also noted at other sites, resulting in the conclusion that track rehabilitation geotextiles are best selected from needle-punched geotextiles.

ASSESSMENT AT SALEM ON CONRAIL TRACK

Three visits at 6-month intervals and one at 45 months were made to a geotextile test site at Salem, Ohio, as a guest of Conrail. At this site six types of nonwoven geotextiles, five with a mass/unit area greater than 500 g/m^2, were installed. During the first site visit the geotextiles were a depth of 150 mm below the base of the ties. The exhuming method was the same as at Loudonville. Again the fouling fines were degraded ballast fines from the ballast adjoining and below the undercut surface. The condition of these geotextiles after 1.5 years is shown in Figure 2.

Two points are worth noting from Figure 2. First is the damage on each side of the area (outlined by shading at the edge of the

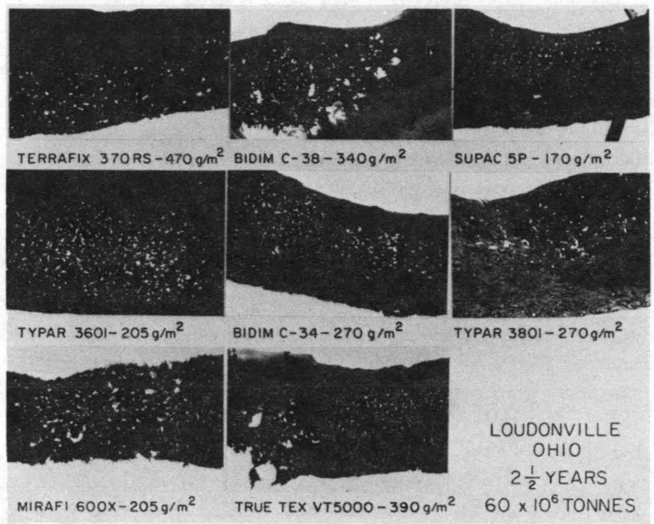

FIGURE 1 Condition of rail seat area of geotextiles exhumed after 30 months from Conrail's Loudonville site.

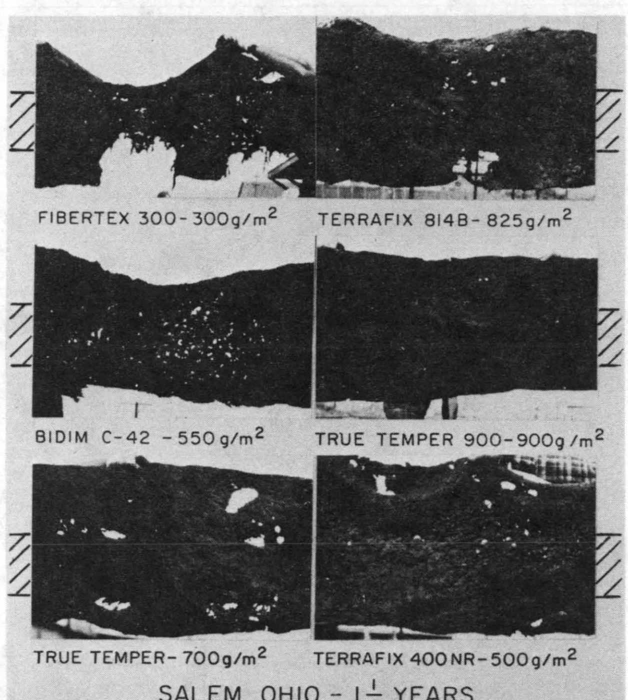

FIGURE 2 Condition of rail seat area of geotextiles exhumed after 18 months from Conrail's Salem site.

photographs) directly below the tie. This damage was done by the tamper tines, supporting the trend of the data that an installation depth of 150 mm below the base of the tie is insufficient. Second is the condition of the area directly below the tie. This area shows damage in the form of holes (not caused by the tampers) in the geotextiles of less than 900 g/m^2 mass/unit area. This suggests that a mass/unit area of at least 900 g/m^2 is needed for a rehabilitation geotextile to remain durable to function as a separation and filtration layer.

INSTALLATION CONSIDERATIONS FOR SELECTION OF TRACK GEOTEXTILES

One aspect of geotextile use that was not appreciated until some time into the project study was the method of track rehabilitation for fouled ballast. In general the track is not removed, but instead the ballast is undercut with either a chainsaw-type blade that extends under the track from one side only, or a chainlike belt feeding down under one side of the track and up the other side. A less used form is to plow or sled the old ballast flat without removing the rail. In this method new ballast is added to raise the rail above its prerehabilitation elevation. In all cases, where the track is not removed, the surface produced has ballast-size particles protruding from the surface. While some of these particles may be removed with a rake, numerous angular particles are left in place, as seen in Figure 3. Figure 3 shows the fouled ballast surface of an undercut turnout where a geotextile is to be installed. Incidently, about 100 mm below this surface is a clean filter sand used to prevent subgrade fouling of the ballast. No subgrade fouling existed at this site.

From observation of the fouled ballast surface onto which the geotextile is to be placed it is clear that a further requirement for track rehabilitation geotextiles (in addition to those already stated) is that the geotextile must be able to span and elongate around the freestanding or protruding sharp ballast particles. Because of the sharpness of the crushed particles, geotextiles that span and cannot elongate are cut from the impact of repetitive axle loading. Thus only geotextiles that can elongate around the particles were found to be satisfactory.

FIGURE 3 Condition of undercut ballast surface showing protruding particles.

A final consideration is the tamper tines used to compact ballast below the tie. These tines project about 130 mm below the base of the tie. As the tines move back and forth ballast particles are moved to some depth, typically about 200 mm below the tie base. Any geotextile used must be placed at a depth greater that 200 mm and be abrasive resistant (i.e., resistant to the abrasion of the relative movement between particles on both sides and in contact with the geotextile caused by tamping or by moving traffic).

A complete outline of problems and recommended techniques for installing geotextiles has been presented elsewhere (*3*) and is beyond the work reported here. Installation technique and careful handling are immensely important. An incorrectly installed geotextile can be a detriment to good performance rather than a help. A well installed, correctly specified geotextile had been observed to be highly cost-effective.

PERFORMANCE CONSIDERATIONS

From the data gathered in the preliminary assessment and from observing geotextiles being installed it was evident that in-track rehabilitation geotextiles are mainly employed as a means of preventing new, clean ballast or old undercut and cleaned ballast from being fouled with fines accumulated in the underlying dirty ballast or dirty subballast (i.e., separation and filtration that requires abrasion resistance). In rare situations fouling is from the subgrade, although all sites visited had considerable depths of ballast and subballast, suggesting that none of the fouling was subgrade fines. In the presence of water most internal contaminating fines below clean or cleaned ballast, subject to repetitive loads, will migrate upward through the track structure. Thus drainage improvement was established as an essential item. Such drainage provisions include the following, as appropriate:

- Internal drainage: Drainage of the track's internal stressed volume, whether ballast, subballast, or subgrade,
- Ditch drainage: Adequate side ditch drainage to deal with surface water, and
- Groundwater drainage: The lowering of the groundwater to increase the subgrade strength.

Clearly geotextiles should never be used in place of good drainage practice. From these considerations a set of functional requirements may be stated.

GEOTEXTILE FUNCTIONAL AND PERFORMANCE REQUIREMENTS

The basic functional and performance requirements of geotextiles in railway bed track rehabilitation can be summarized as follows:

- Drainage: The ability to drain water away from the track roadbed, on a long-term basis, both laterally and by gravity, along the plane of the geotextile without buildup of excessive hydrostatic pressures.
- Filtration: The ability to filter or hold back soil particles while allowing the passage of water.

- Abrasion resistance: The ability to withstand the abrasive forces of moving aggregate caused by the tamping/compacting process during cyclic maintenance, by tamping during initial compaction, and by the passage of trains on a frequent basis.
- Separation: The ability to separate two types of soils of different particle sizes and grading that would readily mix under the influence of repeated loading and water.
- Elongation: The ability to elongate around protruding large gravel-sized particles while resisting rupture or puncture.

REQUIRED PROPERTIES OF GEOTEXTILES

In order to perform the basic functions identified in the functional and performance requirements it has been established from exhumed geotextiles by Raymond and Bathurst (*4*) that the geotextile must have the properties discussed in the following paragraphs.

Permeability

At all sites examined, drainage was considered paramount. With time the ballast above the geotextile will foul. The ability of a geotextile to conduct water through its fiber matrix, whether normal or in its in-plane direction, is essential for good performance. In-plane coefficients of permeability of some new, unused geotextiles have been presented by Gerry and Raymond (*5*). It should be noted that for the woven geotextiles the weave will transmit water in the laboratory but not in the field, where soil penetrates the weave overlaps, closing the water passage existing between the flush boundaries of the permeameter. For unused nonwoven needle-punched geotextiles, the in-plane permeability is close to that of a clean sand. This is large in comparison with the permeability of fine sand, silt and clay produced by ballast degradation, transported sources, and subballast fines that, in the presence of water, migrate upward, fouling the clean ballast. Thus virtually any nonwoven needle-punched geotextile in a clean condition should pass any realistic in-plane permeability criterion.

Geotextiles installed in a track environment are subject to fouling. Tests on newly manufactured specimens should only be used to reject a geotextile that would not perform satisfactorily in the field. Of more value are tests performed on track-fouled geotextiles. Figure 4 shows results of tests conducted on thick nonwoven geotextiles exhumed at 6, 18, and 45 months from Conrail's Salem test site. All the geotextiles are nonwoven and were subject to the same tonnage. It is seen that the loss of permeability under load is related to the degree of fouling measured by the soil content of the exhumed geotextile.

The best predictor of fouling was found to be the geotextile's measured filtration opening size (FOS). The results were similar to those obtained by Gerry and Raymond (*6*) using a 5 percent passing equivalent opening size criteria.

It is concluded that a new geotextile's in-plane permeability was reduced less by products with low FOS. In general these products were constructed of fibers whose linear density was 0.7 tex or less, whose fibers had been tightly mechanically bonded by needle-punching, and were often resin bonded. Note that tex is the mass in milligram/meter length.

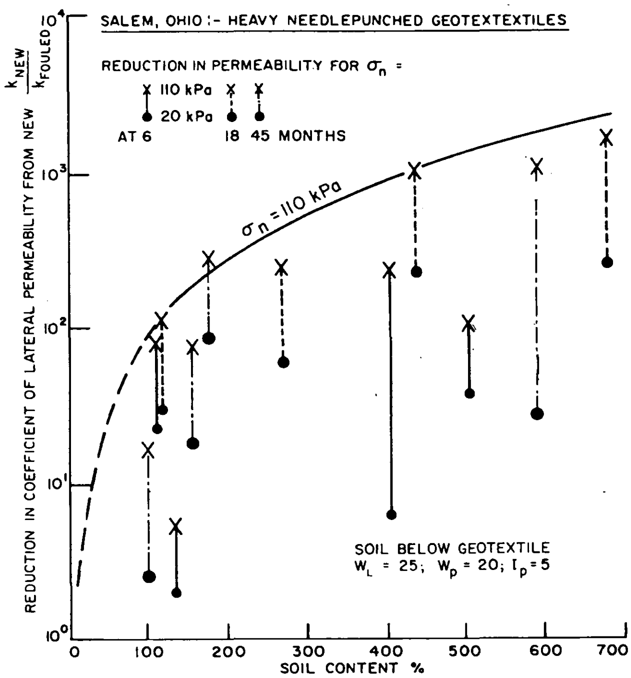

FIGURE 4 Permeability change ratio of exhumed geotextiles heavier than 500 g/m² when new.

Filtration Opening Size

The permeability, filtration, and separation performance of geotextiles is commonly related to one of the following similar quantities: FOS, apparent opening size (AOS), or effective opening size (EOS). Because of the wet environment associated with track geotextiles the FOS is considered the most appropriate test. As just illustrated, the reduction of in-plane permeability of in-track geotextiles due to fouling is dependent on the geotextile's FOS.

In practice soil particles push their way into a geotextile, thus increasing the geotextile's in-track FOS. These penetrating particles are abrasive. The effect of this abrasion is illustrated in Figure 5, which compares two 500-g/m² nonwoven geotextiles (with scrim) of the same trade name and manufacture, one taken from track (250 mm below the base of a tie rail seat) and ultrasonically cleaned and one that is new. They have both been photographed

FIGURE 5 Comparison of new (*left*) and used (*right*) geotextile internal fiber wear.

in front of a bright light. The one taken from below the track shows light through the particle penetration holes, while the new one shows no light. A small FOS will reduce the size of particle that can penetrate the geotextile and hence will reduce the abrasiveness to the geotextile's fibers. Obviously any process that physically bonds fibers so as to increase the resistance to particle penetration will also be beneficial to geotextile durability. These processes are considered to be resin bonding of fibers, heat bonding of fibers, and mechanical bonding by needle-punching.

A further factor that decreases FOS is the fiber size. Hoffman (7) showed that both smaller fibers and decreased porosity reduced a geotextile's EOS. The trends should be valid for a geotextile's FOS. Figure 6 gives results of FOS tests performed on experimental geotextiles of similar mass/unit area and manufacture except for fiber size. The results confirm the general trend found by Hoffman regarding fiber size.

In conclusion durability will be increased by reducing the track geotextile's FOS. This will be enhanced by resin, heat, or mechanical bonding, smaller fiber size, and decreased geotextile porosity.

Abrasion Resistance

A geotextile placed in a track environment must resist abrasion from large stone particle movement on its surfaces and from small particles that penetrate its fiber matrix. If the geotextile is installed at too shallow a depth the tamper tines will cut and tear the geotextile, as seen in Figure 2. At depths just below the penetration of the tamper tines the ballast is agitated during tamping. At even greater depths particle movement, although less abrasive, still occurs. Geotextiles in a track environment must clearly be abrasive resistant. An assessment of a geotextile's ability to resist abrasion was initially reported by Van Dine et al. (8) and extended by Costa and Raymond (9). Costa and Raymond recommended testing in the laboratory using the Taber Abrasor (ASTM D-3884, Rotary Platform Double Head Method) fitted with two H-18 Calibrade stones, each carrying a 1000-g mass. Figure 7 shows the results of abrasion testing on a 1000-g/m² needle-punched polyester fiber geotextile using different percentages of resin treatment. Clearly even a little resin caused a major increase in abrasion resistance. The porosity of the untreated geotextile is about 85 percent. Because the resin has a specific gravity similar to polyester the resin treatment has little effect on the geotextile's porosity and in-plane permeability. Excess resin makes the geotextile too stiff to handle and install in the field, limiting the amount to 20 percent by weight.

The degree of needle-punching a nonwoven needle-punched geotextile receives during manufacture determines the amount of mechanical interlock between fibers, which influences the geotextile abrasion resistance. Results were obtained from abrasion tests performed on a number of geotextiles manufactured using a variable amount of needle-punching. While needle size, needle penetration, and other factors are manufacturing variables, the amount of needling was found to be important. From the test results a minimum of 80 penetrations per square centimeter (80 p/cm²) should be specified. Further factors investigated included fiber strength and length. For the best mechanical fiber interlock a 100-mm minimum was established along with a minimum fiber strength of 40 μN/tex.

In conclusion both the amount of needling during manufacture and the resin treatment increase the abrasion resistance of geotextiles subject to particle penetration.

Impact Resistance

When ballast is placed it is dropped about 1 m onto the geotextile. No evidence was obtained that suggested that geotextiles that meet an abrasion criterion would not be suitable to resist impact.

Elongation

Undercut ballast has protruding aggregate particles, as illustrated in Figure 3. Track geotextiles must be able to elongate around

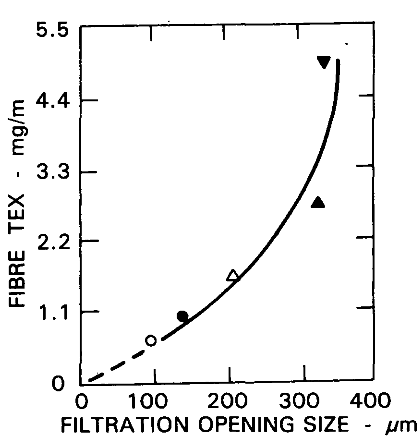

FIGURE 6 Effect of polyester fiber tex on measured filtration opening size of similarly manufactured 600 g/m² mass/unit area nonwoven needle-punched (80 p/cm²) geotextiles.

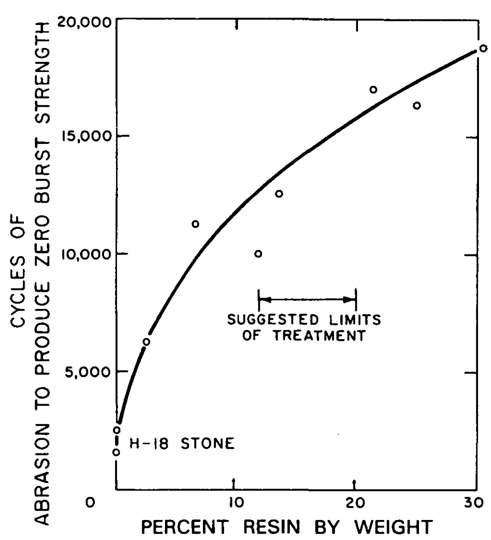

FIGURE 7 Cycles of abrasion required to cause zero burst strength for a 1000 g/m² polyester geotextile treated with different percentages by weight of resin.

these particles. If a nonwoven geotextile is reinforced with a woven scrim, protruding particles were found to rupture the scrim. The scrim, however, prevented adjoining portions of the geotextile from elongating and the particles penetrated through the geotextile, as seen in Figure 8. On the other hand exhumed nonwoven geotextiles that elongate 60 percent or more in a grab test (ASTM D-4632) were found to be unruptured.

In conclusion a track geotextile should elongate 60 percent or more in a grab test (ASTM D-4632).

Chemical Resistance and Polymer Type

Little is known about the long-term chemical effects on polymer types in a track environment, in particular the effects of long-term seepage of fuel oil and herbicides common to most track. Resin treatment is believed to protect fibers from the detrimental effects of track pollutants. The only known data relating to the time/traffic deterioration of geotextiles in a track environment were obtained from Conrail's test sections at Loudonville and Salem, Ohio. Mullen burst test (ASTM D751) results from samples extracted at 6-month intervals after installation are shown in Figure 9. Figure 9 shows the burst strength ratios (exhumed burst strength–initial burst strength) against time. The data were subject to regression analysis (including the initial 100 percent value), and the regression fits are shown along with their statistical significance in the figure. Examination of plotted data shows that only well-needled polyester fiber materials showed little to no loss of burst strength and were statistically significant. These were Truetex VT5000 and Terrafix 370 (*RS* at r^2 = 99 percent significance) from Loudonville, and True Temper 900 (at r^2 = 99 percent significance) and True Temper 700 (at r^2 = 90 percent significance) from Salem. The other polyester fiber materials were the three Bidim products that were manufactured as spun-bonded geotextiles with only a small amount of needle-punching. All the other geotextiles, made partly or wholly from other than polyester fiber, recorded between 25 and 70 percent loss in burst strength. The test data for these other geotextiles showed considerable scatter, having a statistical significance between 80 and 90 percent.

It is concluded from these initial data that the most environmentally stable geotextiles for these two Ohio sites were manufactured as well-needled geotextiles from polyester fibers.

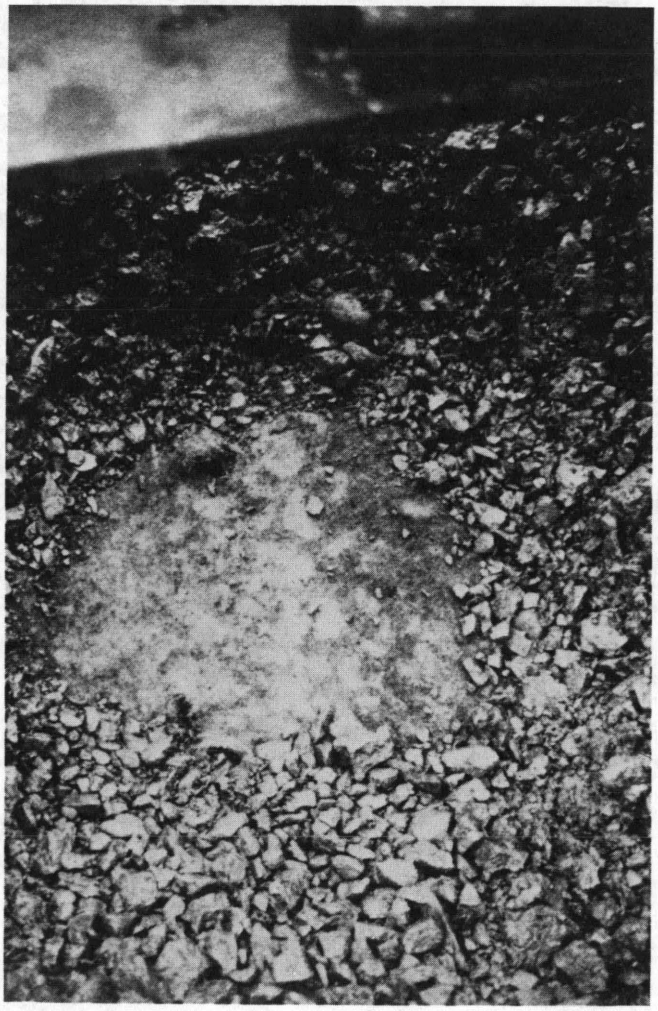

FIGURE 8 Ballast particle penetrating a 1000 g/m² composite (nonwoven with woven scrim) geotextile due to woven's inability to elongate.

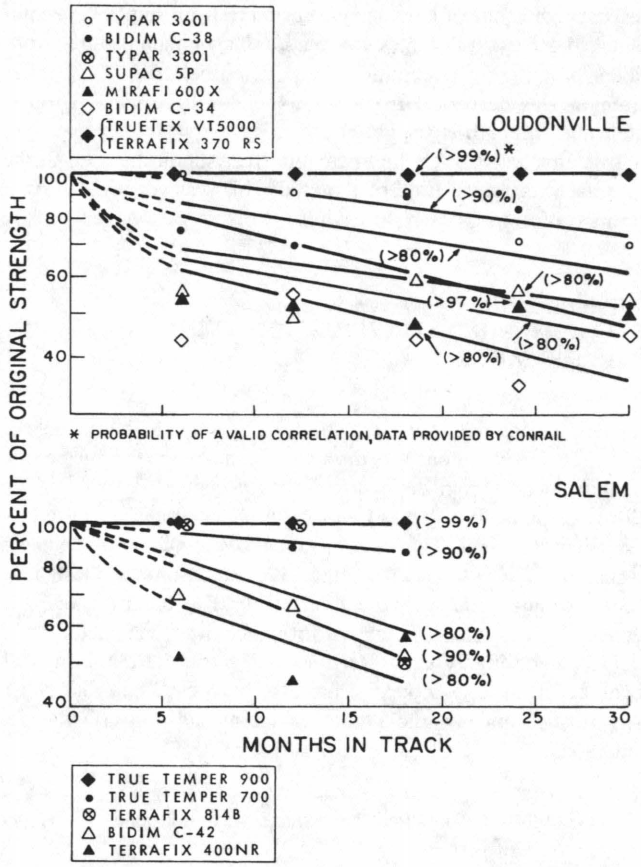

FIGURE 9 Relationship of time variation on Mullen burst strength of exhumed geotextiles from Conrail's two sites.

Fiber Strength

The unit strength or failure stress of the individual fiber is perhaps the key to a major portion of a geotextile's strength and abrasion resistance. Results of laboratory abrasion tests on similarly needle-punched geotextiles of the same mass/unit area manufactured from fibers of different strengths showed a tenfold loss as the fiber strength was decreased from 40 μN/tex to 10 μN/tex. Clearly, high fiber strength is important.

It is concluded that a high-strength fiber should be used in the manufacture. At the time of the study this was represented by a strength of not less than 40 μN/tex.

RECOMMENDED SPECIFICATION AND PERFORMANCE

In 1981 a possible track rehabilitation geotextile based on the previous considerations was discussed with a number of geotextile manufacturers. From these discussions a geotextile specification (listed in point form below) was recommended and was used by Canadian Railways. This has been the basis of about 50 geotextile installations per year for more than 12 years. Some of these have been exhumed and all were intact (*10*). The ballast above the geotextile was clean, track performance was satisfactory and judged to be highly cost-effective, and geotextile durability has been excellent. The geotextile has also been used on other North American Company tracks with excellent and cost-effective results (*11*).

- Type: Needle-punched nonwoven with 80 penetrations per cm^2 (800 p/cm^2) or greater.
- Fiber size: 0.7 tex or less.
- Fiber strength: 40 μN/tex or greater.
- Fiber polymer: Polyester.
- Yarn length: 100 mm or greater.
- Filtration opening size: 75 μm or less.
- In-plane coefficient of permeability: 50 μm/sec or greater.
- Elongation: Sixty percent or more to ASTM D4632.
- Seams: No longitudinal seams permitted.
- Color: Must not cause "snow blindness" during installation.
- Packaging: Must be weatherproofed and clearly identified at both ends stating manufacturer, width, length, type of geotextile, date of manufacture.
- Wrapping: 8-mil black polyethylene or similar.
- Abrasion resistance: 1050 g/m^2 geotextile must withstand 200 kPa on 102-mm burst sample after 5,000 revolutions of H-18 stones each loaded with 1000 g of rotary platform double-head abrasor (ASTM D3884).
- Width and length without seaming: To be specified by client.
- Fiber bonding by resin treatment or similar: 5 to 20 percent by weight low-modulus acrylic resin or other suitable non-water-soluble resin that leaves the geotextile pliable.
- Mass: 1050 g/m^2 or greater for track rehabilitation without the use of capping sand.

CONCLUSIONS

From the 1981 surficial inspection of Canadian tracks it is clear that if a nonwoven geotextile were used for track rehabilitation, it would need to have a mass/unit area greater than 500 g/m^2. This assessment was confirmed by the excavations at other locations, such as those presented herein for Loudonville, Ohio.

Excavations made on Canadian tracks of geotextiles have a mass/unit area of at least 500 g/m^2 confirmed this conclusion, as even when 500 g/m^2 samples were exhumed at a depth of 350 mm there was damage. This assessment was confirmed by the excavations at other locations, such as those presented herein for Salem, Ohio.

From the excavations made on Canadian tracks in the summer and fall of 1981 it was concluded that geotextiles should be installed at a depth of 250 to 300 mm below the tie base and tamping should not be permitted until that depth of ballast was in place. The conclusion was confirmed by later excavations made at numerous other sites, in Canada, the United States, and other areas of the world.

The excavations at Salem, Ohio, indicated that a mass/unit area of at least 900 g/m^2 is needed for a rehabilitation geotextile to remain durable to function as a separation and filtration layer.

In addition, laboratory studies were carried out and observations made of geotextile installation techniques. All these factors resulted, in late 1981, in a geotextile specification for a track rehabilitation geotextile, the main requirements of which are listed in the previous section.

The specification has been in use since 1981 in Canadian National Rail's Maritime Region, where about 50 installations have been made annually. Excellent performance has been obtained, and the few excavations made to exhume geotextiles manufactured to this specification have all shown complete geotextile integrity. Geotextiles installed without a capping sand, meeting the specification, are showing excellent durability after 12 years of service in the physically harsh environment of North American track.

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REFERENCES

1. Raymond, G. P., W. J. Purdy, B. S. Gerry, and C. Fitzpatrick. *Geotextiles in Railway Track Rehabilitation Applications.* Report 81-16. Canadian Institute of Guided Ground Transport, Kingston, 1981.
2. Raymond, G. P., and B. S. Gerry. *Geotextile Analysis of Two Geotextile Sites.* Report 82-11. Canadian Institute of Guided Ground Transport, Kingston, 1982.
3. Raymond, G. P. Installation Factors Affecting Performance of Railroad Geotextiles. In *Transportation Research Record 1071,* TRB, National Research Council, Washington, D.C., 1986, pp. 64–71.
4. Raymond, G. P., and R. J. Bathurst. Tests on Exhumed Railway Track Geotextiles. *Proc., 4th International Conference on Geotextiles and Geomembranes,* Vol. 1, The Hague, The Netherlands, 1990, pp. 197–202.
5. Gerry, B. S., and G. P. Raymond. The In-Plane Permeability of Geotextiles. *Geotechnical Testing Journal,* ASTM, Vol. 6, No. 4, 1983, pp. 181–189.

6. Gerry, B. S., and G. P. Raymond. Equivalent Opening Size of Geotextiles. *Geotechnical Testing Journal*, ASTM, Vol. 6, No. 2, 1983, pp. 53–63.
7. Hoffman, C. S., Jr. An Empirical Model for the Design of Fibrous Filter Media. *Proc., 11th INDA Conference*, New York, 1983, pp. 93–105.
8. Van Dine, D., S. E. Williams, and G. P. Raymond. An Evaluation of Abrasion Tests for Geotextiles. *Proc., 2nd International Conference on Geotextiles*, Vol. 3, pp. 811–816.
9. Costa, J. M. A., and G. P. Raymond. Burst Tester for Geotextile Bidirectional Strength. *Geotechnical Testing Journal*, ASTM, Vol. 6, No. 3, 1983, pp. 122–143.
10. Raymond, G. P. *Subblast and Geotextiles for Railway Track Support Separation Applications.* Report 85-12. Canadian Institute of Guided Ground Transport, Kingston, 1985.
11. Raymond, G. P. ATSF 1980 El Dorado Line Change Failure/Rehabilitation. *Journal of Geotechnical Engineering*, ASCE Vol. 117, No. 8, 1991, pp. 1191–1207.