U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

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DOT HS 809 961 November 2005

A New Brake Lining Marking System for Truck Tractors

Report to Congress
March 2004

TABLE OF CONTENTS

I. BACKGROUND 1

A. Original Congressional Request 1

B. Issues 1

C. Prior Efforts to Address Issues 3

II. ACTION TAKEN BY NHTSA 9

III. SUMMARY OF ORNL REPORT 9

IV. POSSIBLE FUTURE ACTIVITIES 10

A. Initiate a Tracking Program for Braking Linings Supplied with New Trucks 10

B. Review Dynamometer Data 10

C. Educate those with a Need to Know 11

D. Identify a Database Custodian 11

E. Provide a Website and Data Gateway 11

F. Continue to Develop a Cost-Effective Lining Material Wear Test 12

G. Develop Operating Use Spectra 12

H. Develop a Spectrum Test Method 12

V. CONCLUSIONS 13

I. Background:

A. Original Congressional Request

Senate Report 107-38, accompanying S. 1178, a bill making appropriations for the Department of Transportation and related agencies for fiscal year 2002, states the following (at page 96):

> *The Committee on Appropriations is aware that NHTSA has issued regulations regarding stopping performance of medium and heavy-duty trucks. The Committee understands that to remain in compliance with these rules, replacement brake lining must have the same friction rating as that of the original brake lining. The Committee further understands that a uniform method for measuring brake lining friction and permanently marking the lining with that rating is unavailable and thus directs NHTSA to perform research into rating brake lining friction and permanently marking the lining with that rating. Within the funds provided, the Committee provides $300,000 for research into the rating of brake lining friction in order to facilitate a rulemaking in this area.*

B. Issues

We would like to direct the Committee's attention to the fact that National Highway Traffic Safety Administration (NHTSA) standards, which apply to equipment (both original and replacement equipment), generally cover those types of items that can be used in many different vehicle lines, that are frequently replaced or sold separately, and that can be independently tested. These include such items as brake hoses (Standard 106), lamps and reflectors (Standard 108), tires (Standards 109, 117, and 119), windows and windshields (Standard 205), safety belt assemblies (Standard 209), child safety seats (Standard 213), and motorcycle safety helmets (Standard 218). Other safety systems require testing in a full-vehicle context, and our safety standards are applied to the vehicle rather than the component. This is the case with brake linings. NHTSA has standards for vehicle braking performance (Federal Motor Vehicle Safety Standard [FMVSS] Nos. 105 and 121) but does not have standards for new brake lining performance.

While the current standards do not apply to new or replacement brake linings, NHTSA has full authority to pursue any alleged safety problems with brake linings or any other vehicle components under the "defects" provision of the Safety Act. If evidence demonstrated that certain brake linings presented an unreasonable risk to motor vehicle safety, the agency could order the manufacturer of such linings to repair or replace such linings. At the present time, however, we are not aware of a safety problem with replacement brake linings that would warrant the commencement of a defects investigation.

For many years, the friction materials industry, original equipment manufacturers, truck owners and operators, and NHTSA have struggled to discover a consistent rating scheme for brake materials that meaningfully relates to their on-vehicle performance. Such a rating scheme could be used for material selection, material development, and after-market product qualification. A number of Society of Automotive Engineers (SAE) practices and NHTSA documents have emerged over the years, and some of these have undergone a continuing series of modifications to improve their usefulness. There are thousands of person-hours invested in their development. Some test methods have also fallen out of favor, yet they are so engrained in State government purchasing regulations that they are problematic to remove. Despite their rigor and complexity, current test protocols have yet to completely satisfy the need for simple, functional metrics, for qualifying and selecting friction brake materials for trucks.

While simple to state, achieving this objective in practice is both complex and difficult for the following reasons:

- Frictional behavior is a characteristic of *both* the nature of the contacting materials *and* the system in which they must operate; thus, any friction test for materials must be mechanical system-specific.
- Brake materials must perform under a wide variety of operating conditions (contact pressures, sliding speeds, length of applies, ambient temperatures, and surrounding environments).
- Brake materials must offer long-term durability (wear resistance) as well as controlled frictional behavior.
- Differences in vehicle braking system designs subject materials to different mechanical and thermal loads; therefore, no test yet devised can simulate the entire range of friction material use conditions.
- Vehicle operational profiles and driving habits can significantly vary the demands on brake materials.
- Long-term friction material degradation is difficult to simulate in cost-effective, short-duration tests.
- Friction materials are complex composite materials whose homogeneity can sometimes vary from lot to lot. This raises the question of what size test sample (number of specimens) will satisfactorily represent the total population.

There are many challenges inherent in meeting the research goals of this report, as follows:

- developing a test method that quantifies the most important braking performance characteristics of the materials;
- verifying that test results correlate satisfactorily with on-vehicle response
- providing, within a single testing protocol, a sufficient quantity of information to detect differences between different materials, including significant differences between lots of the same type of material;
- minimizing operator training and reduce subjectivity in interpreting test results

- ensuring that the results are repeatable and reproducible (within and between organizations);
- minimizing time, cost, and complexity of the test procedure; and
- creating an effective test that is both useful and acceptable to the trucking industry and its suppliers.

There is a distinct difference between a *simulative* test and a *qualification* test. A simulative test attempts to faithfully reproduce all the operating variables that could influence the output parameters of interest, but a qualification test needs only to provide a metric (or set of metrics) that will qualify a material for use. Therefore, a qualification test does not have to simulate every aspect of the intended use as long as it provides a means to establish the degrees of suitability for use. For example, hardness tests are often used to verify heat treatments for spur gear blanks, but the hardness test itself does not exactly simulate the operating conditions of a spur gear. Usefulness does not equate to simulation.

Brake material tests range widely in size scale, sophistication, and procedural complexity. Some tests use constant-pressure (or constant torque), constant-speed, and continuous drags (“applications”). Some procedures have multiple test segments that use different speeds, temperatures, and application pressures. Some tests use small coupons cut from pads or drums and others use full-scale hardware. A list of some of the types of tests follows. Clearly, they vary in testing time, ease of performance, need for calibration, amount of data collected, cost per individual material evaluation, and means of data reduction and interpretation. Some, if not most of these tests, have certain specific measures of performance that may not be easily compared to those obtained in other kinds of brake tests.

Full-vehicle, on-road tests (with instrumented brakes)
Full-vehicle, test track tests (with instrumented brakes)
Full-vehicle, in-ground sensor plate balance tests
Full-vehicle, drive-on, single- or multiple-axle roller tests
Chassis dynamometer tests
Single-wheel (tire-on-drum or tire-on-belt) tests
Inertial dynamometer tests of brake hardware
Motored dynamometer tests of brake hardware
Specialized component tests (for example, tests for caliper performance)
Sub-scale tests of material coupons or undersized discs/drums
Friction and wear lab tests that use simple geometries (block-on-ring, pin-on-disk, etc.)

In general, the farther up the above list, the more complex and expensive it is to control each test and obtain repeatable results. Conversely, the lower down the list, the less the testing machine resembles an actual braking system. The degree of instrumentation used in these tests varies as well.

C. Prior Efforts to Address Issues

SAE recommended practice for rating heavy-duty vehicle brake block performance, SAE Recommended Practice J661a—*Brake Block Quality Control Test Procedure* (approved in 1958 and completely revised in 1987) was one of the first standard developed by SAE in this area. The SAE also had a recommended practice for marking heavy-vehicle brake blocks with performance data based on the results from the J661a procedure. This SAE Recommended Practice, J866—*Friction Coefficient System For Brake Blocks*, designated the normal temperature and high temperature performance of given block material, and specified procedures for printing the J661 performance ratings on the edge of the lining.

Based on its evaluations of the J661a test procedures, the trucking industry concluded that the levels of repeatability and reproducibility of the SAE standards were unacceptably low. Additionally, the trucking industry determined that the test procedure was not realistic since it did not use a full-scale brake block or other full-scale heavy-duty vehicle brake hardware. The J866 specifications and ratings were also deemed unacceptable by users. According to ATA, a given SAE J866 rating covered such a wide range of brake lining performance that vehicle brake balance problems were possible using blocks with the same rating. In addition, the J866 procedure for marking the lining did not result in permanent markings. As a result, vehicle operators and maintenance personnel often could not identify the performance ratings on in-service linings.

Since the SAE recommended practices for testing brake lining effectiveness and the procedure for marking the lining with an effectiveness value were unacceptable to the industry, the SAE initiated the development of new procedures in the mid-1980s. At that time, the SAE Brake Committee, Brake Effectiveness Task Force, initiated development of a new procedure for evaluation of the effectiveness of heavy-vehicle brake linings, SAE Recommended Practice J1802—*Brake Block Effectiveness Rating.* The SAE began development of a new specification for rating the effectiveness of brake linings and permanently labeling the linings with information concerning the effectiveness (torque output), SAE J1801, *Brake Effectiveness Marking for Brake Blocks.*

In 1990, NHTSA began working with SAE and the Heavy-Duty Brake Manufacturers Council (HDBMC) in the development and evaluation of SAE J1801 and J1802 and the development of possible improvements to them. In that year, dynamometer testing to an early version of J1802 was conducted by three different test facilities using their own funds (Greening Labs, Link Engineering, and NHTSA's Vehicle Research and Test Center, [VRTC]). The testing produced significantly different effectiveness ratings for brake blocks that were manufactured to have essentially the same performance characteristics. It could not be determined from this testing whether the differences in effectiveness ratings were due to the variations in actual lining performance, differences in test fixtures, or differences in the dynamometers at each facility.

In order to determine the cause of the significant differences in the ratings of brake lining effectiveness produced by the three facilities, a round-robin series of brake lining testing was conducted. Nine organizations with brake dynamometer testing facilities, including the agency's VRTC, volunteered to participate in the project using their own funds. For this testing, which was conducted in 1991–1992, a single test fixture that included a brake drum and brake blocks was tested at each facility. After completion of testing at one facility, the brake assembly and brake blocks were forwarded to another of the participating facilities. The primary purpose of this series of tests was to determine the variability of the test results due to differences in the dynamometers at each facility. The test results revealed a small (10–15%) variation in test results that could be attributed to the differences in the dynamometers at each facility.

Based on the results of the single fixture testing results, VRTC conducted a second series of voluntary round robin testing in 1992 and 1993 to evaluate the repeatability and reproducibility of the J1802 test procedure. Six brake-testing facilities participated in this test series, which involved determining the normal and high temperature brake effectiveness ratings for three brake block materials using the J1802 test procedure. Each facility was supplied with a brake drum and several sets of blocks. The blocks supplied to each facility by a given manufacturer were from the same batch or block manufacturing cycle. Although the entire test series was not completed by all participants, sufficient data were produced for the agency to determine that there was as much as a 50-percent variation of the effectiveness ratings for the same brake block material when tested at different facilities, and a 20-percent variation in the effectiveness ratings for the same block material during different tests at the same facility.

The first round-robin test series indicated that the differences in the test facility dynamometers resulted in as much a 10- to 15-percent difference in brake block effectiveness values. The increased variation in effectiveness ratings experienced in the second round robin was attributed to other test parameters such as test fixture, the method of brake assembly installation on the test fixture, and the brake preparation (brake burnishing and brake block grinding).

In 1996, NHTSA initiated a project aimed at developing a brake-block-rating scheme that could be used to provide information to consumers about the effectiveness of heavy-truck brake blocks. A one-year feasibility project was conducted at VRTC, which developed several effectiveness test components and test procedures that were different from those in SAE J1802. These differences included variations in burnish cycles, the number of effectiveness stops, and block precutting profiles. New test fixture components and effectiveness test procedures were used to test one original-equipment brake block and several aftermarket blocks. Although the VRTC-developed fixture and procedure were successful in eliminating some of the effectiveness variability experienced with SAE J1802, the modified procedure still resulted in considerable variation in block effectiveness. There was a 20- to 30-percent variation in effectiveness rating results when a single brake block was tested 10 consecutive times with the new brake components and modified procedures. VRTC then evaluated the variability that might result from using different brake blocks. An original-equipment block and two aftermarket brake blocks recommended as replacement blocks were tested. The variability of the effectiveness rating for the original equipment block was about 10 percent. The variability of the test results for the two aftermarket replacement blocks was 18 to 25 percent for one block and 8 to 25 percent for the other.

A computer study funded by the Federal Highway Administration (FHWA) examined the effect of several S-cam-type brake parameters on the brake output torque (effectiveness). This computer simulation study, conducted by the University of Michigan Transportation Research Institute (UMTRI), and completed in 1999, found that small variations in the test fixtures could cause significant changes in brake output torque. The study further stated that the brake equilibrium reached during burnish could be disturbed when brake actuation pressure is above or below the burnish pressure. This no-equilibrium condition, caused by differential block wear between the leading and trailing block at equilibrium, may result in the instability of the brake effectiveness ratings experienced in the SAE J1802 testing. The study concluded by recommending that the computer model be extended to include block wear properties to further examine the SAE J1802 brake effectiveness variations.

Although SAE J1802 was published in 1993, the research conducted by NHTSA and the other test facilities has consistently indicated that the procedure is not highly accurate at measuring brake block torque output. Consequently, very few brake blocks are marked according to the marking procedure specified in SAE J1801. Resistance to use of the J1802 rating and the J1801 markings is based on the belief that the J1802 ratings suffer from high variability in test results and are not a good predictor of brake block effectiveness.

A computer simulation study funded by the Federal Highway Administration examined the effect of several S-cam-type brake parameters on the brake output torque (effectiveness). This computer simulation study conducted by the University of Michigan Transportation Research Institute, which was completed in 1999, found that small variations in the test fixtures could cause significant changes in brake output torque. The study further stated that the brake equilibrium reached during burnish could be disturbed when brake actuation pressure is above or below the burnish pressure. This nonequilibrium condition, which could be caused by differential lining wear between the leading and trailing lining at equilibrium, may result in the instability of the brake effectiveness ratings experienced in the SAE J1802 testing. The study concluded by recommending that the computer model be extended to include lining wear properties to further examine the SAE J1802 brake effectiveness variations. These recommendations have not been fully explored by NHTSA or anyone else, to our knowledge. Two fixtures were tested by NHTSA on a brake dynamometer. Each fixture was tested with two sets of two types of brake lining blocks. A single operator performed the tests on a single dynamometer to reduce the number of sources of variability. While only a very limited number of tests were performed, the results suggest that much of the variability found in the past round-robin testing may have come from sources other than the test fixtures (dynamometer, operator, slightly different set-up procedures, brake lining and/or brake drum material differences, etc.).

Although SAE J1802 was published in 1993, the research conducted by NHTSA and the other test facilities has consistently indicated that the procedure is not highly accurate at measuring brake lining torque output. Consequently, very few brake linings are marked according to the marking procedure specified in SAE J1801. Resistance to use of the)1802 rating and the J1801 markings is based on the belief that the J1802 ratings suffer from high variability in test results and are not a good predictor of brake lining effectiveness.

NHTSA received two petitions for rulemaking requesting issuance of standards for brake linings, one from the ATA and the other from a private individual, Ralph Grabowsky. In March 1989, NHTSA partially granted and partially denied Grabowsky's petition, agreeing to consider beginning rulemaking to develop a standard for marking, identifying, and rating the effectiveness of heavy-truck brake linings. After granting these petitions, the agency initiated a number of studies to determine the feasibility of developing effectiveness ratings for heavy-truck brake linings. After examining the data developed from its research, as well as examining voluntary standards for heavy-truck brake linings, NHTSA has determined that it is unlikely that a suitable test procedure for comparing and rating brake linings can be developed with currently available test equipment and procedures. Accordingly, the agency terminated this rulemaking action on July 9, 2002.

II. Action Taken by NHTSA in Response to Appropriations Language

As directed by Congress, $300,000 of the funds provided for research in fiscal year 2002 has been used for research into brake lining friction. A contract was awarded to Oak Ridge National Laboratory (ORNL) for this work. This project was sponsored by the Department of Transportation under an interagency agreement with the Department of Energy (Agreement 2334-R486-1). ORNL was chosen for this task because of the laboratory's expertise in friction materials. ORNL was also chosen for this task because it had not been involved in previous research conducted by NHTSA, private industry, and various other institutions over the past 30 years. For this reason, it was felt that ORNL could possibly offer some fresh insight to the problems involving brake lining grading.

The objectives of this project undertaken by ORNL were to research current methods for testing truck tractor brake lining performance, to identify which of them would be suitable for grading aftermarket products, to identify needs for improved lining test methods, and to propose a marking code and methodology for identifying replacement lining products in a way that would enable small and large truck fleets to select replacement linings for their vehicles.

III. Summary of ORNL Report

ORNL has submitted a research report to NHTSA. After presenting numerous revised "straw men" for review, and based on iterations and discussions with industry engineers and fleet operators, a proposed lining marking code structure has been suggested by ORNL. This designation would be displayed on the lining itself or printed on its shipping box. This approach carries with it a need to educate the industry on its use and a long-term obligation to maintain a database of lining test results so that the full set of test data need not be contained somewhere on the lining or on its shipping box.

ORNL has suggested a "near-term plan," which would use results from current test methods, namely those based on NHTSA's FMVSS 121, with which the industry is already familiar. Since future changes in lining evaluation methods are likely, the lining marking plan described by ORNL has been designed with the flexibility to be modified later if new or improved test methods are developed. ORNL did not specify: (1) what information should be marked on brake linings, and (2) how to mark brake linings.

ORNL's complete report is attached.

IV. Possible Future Activities

Eight possible future activities are identified and discussed by ORNL. These are summarized below. Five pertain to the near-term and the last three to the longer-term. Some of these activities could be initiated using the remaining project funds (for example, items B, D, and F). Others would require additional investments in funding. Potential follow-up activities and levels of effort in person-years (PY) are indicated in brackets [ ]. Working partnerships and commitments on the part of the trucking industry and its suppliers would be key in the implementation of these recommendations. Therefore, the time needed to implement these recommendations would depend to a large degree on the level of participation of industry partners.

A. Initiate a Tracking Program for Brake Linings Supplied with New Trucks

Truck manufacturers could be asked to provide information, axle-by-axle, on the lining types that were supplied as original vehicle equipment. This information could be carried on the vehicle, for example, on a doorjamb sticker or a code in the electronics control unit. The information would contain the proposed lining code. The method for marking the code on the vehicle and the linings themselves needs to be determined.

[A.1 Determine how to implement a practical method for tracking the lining type provided on new trucks and trailers. 1 PY effort for 2 years.]

[A.2 Investigate and recommend practical methods to physically mark brake linings so that the code is still readable when a replacement is required. 1 PY effort for 1 year.]

B. Review Dynamometer Data

The near-term version of the marking code would use torque data obtained under the FMVSS 121 dynamometer test procedure under two apply pressures (20 psi and 80 psi). This data would have to be obtained for a variety of current lining products to determine how many different torque levels (1, 2, 3, 4, etc.) are technically justified to be used for code segment (f) in the marking system proposed by ORNL.

[B.1 Contact sources of FMVSS 121 lining data to obtain 20 psi and 80 psi torque data for a variety of linings. Analyze the range and distribution of this data to help select the number of levels into which the data is divided in marking code segment (f). 1/2 PY effort for 1 year.][B.2 Conduct a more extensive evaluation of existing FMVSS 121 data to determine how the data could be clearly represented and displayed in a more comprehensive public database on lining performance. Provide the information to the developer of the educational software package (see recommendation C.1). 1 PY effort for 1 year.]

C. Educate Those With a Need to Know

Implement a trucking industry education program about the new code system and the lining data that supports it. Methods include (a) presentations to industry groups, (b) trade magazine articles, (c) free pamphlets for distribution to dealers and truck stops, and (d) Internet Web sites. Private industry, the Department of Transportation, or both, could fund the online educational effort. On the basis of preliminary discussions, this educational Web site could be hosted by the Technology and Maintenance Council (TMC) of the ATA.

[C.1 Develop educational software for the new lining code system and implement it in hard copy and via the Internet. 1/2 PY effort for 6 months, following acceptance of the lining code.]

[C.2 Continuing education on the lining code and how to use it can be done through short courses offered by trade organizations.]

D. Identify a Database Custodian

The custodian of the test data for specific linings may be a trucking industry organization like the TMC. It makes sense to have both the lining data and the educational material linked through the same Internet Web site.

E. Provide a Website and Data Gateway

The TMC could be approached as the prime candidate to host and maintain a website that educates users on the new lining marking system and provides links to a lining test database that supports marking code segment (f). Ideally, the supporting database would be searchable online, based on any of the individual code segments or a combination of segments in the marking code.

[E.1 Set up a Web site and populate the supporting database with lining test data from one or more validated sources of FMVSS 121 data. 2 PY effort for 2 years.]

F. Continue to Develop a Cost-Effective Lining Material Wear Test

Work could continue on developing the relatively simple lining wear test prototyped at ORNL. This would involve obtaining additional data on several linings and investigating the degree to which laboratory wear test results agree with fleet experience with the same kind of lining. If successful, the test could be standardized either under the American Society for Testing and Materials (ASTM) (Committee G-2 on Wear and Erosion) or SAE (Brake Linings Committee), and additional units of the test apparatus could be commercially produced.

[F.1 Establish the final testing protocol, then obtain wear-test lining materials whose performance covers a range of durability. 1.5 PY effort distributed over 2 years.]

[F.2 If results warrant, prepare an ASTM Standard Practice describing the lining wear test and work through Committee G-2 on Wear and Erosion to standardize it.1/2 PY effort distributed over 2 years.]

G. Develop Operating Use Spectra

To enable the development of vocation-related test protocols, a longer-term program could be initiated to collect data on the operating conditions of brakes on selected vehicles. It is suggested that this work would begin with three types of vehicles: (1) long-haul tractor-trailers, (2) school buses, and (3) straight trucks for local delivery. [GA Develop operating spectra for three representative vehicles through instrumenting test vehicles or accessing existing data. 2 PY effort over 2 years.]

H. Develop a Spectrum Test Method.

A laboratory test system, on which the operating profiles of various vehicles can be programmed and applied, could be selected and developed. This could be based on an existing test or a new system. Cost, accessibility to testing facilities, and potential for standardization would be prime considerations. Industry (in-kind) contributions (access to facilities and technical advice) would be critical to support this effort. If successful, the data from this test would replace that used for the near-term rating code, segment (f).

[H.1 Develop test machine and conduct spectrum tests to simulate the operating profiles defined by the work following recommendation G.1. 3 PY effort over 3 years.]

V. Conclusions

In summary, NHTSA recommends that agency research on the issue of friction rating for replacement brake linings be discontinued for the following reasons:

1. The agency has not been able to identify crashes resulting from replacement brake linings that have different characteristics from OE linings. NHTSA is also not aware of any study that quantifies the cost and benefits of any

potential rulemaking action based on friction rating. Our conclusion is that brake lining wear that can be affected by brake lining characteristics is primarily an economic issue rather than a safety issue.

2. NHTSA's FMVSS 121 prescribes brake performance requirements that must be met by the vehicle. There are no separate requirements for brake lining friction ratings for new vehicles. Heavy-duty vehicle brake systems are designed such that the performance of replacement linings does not compromise the braking performance of the vehicle.

3. Concern about the possibility of heavy-duty-vehicle wheel lock-up and the resultant potential for vehicle instability was one of the primary reasons for raising this issue in the past. In theory, using brake linings with similar effectiveness on each axle could reduce the risk of instability. In situations where brake linings have different friction characteristics, the braked wheels would decelerate at different rates. This problem has been addressed and mitigated to a great extent by the requirement for antilock brakes established by NHTSA, which are now standard equipment on all new heavy vehicles.

4. Since 1968, NHTSA, along with the SAE, the Technology and Maintenance Council, and other industry groups has tried to develop a test of brake lining friction that would adequately characterize and rate replacement linings. Several recommended practices have resulted from this extensive effort, such as SAE Recommended Practices J1801 and J1802 and TMC Recommended Practice 628. NHTSA has concluded that these recommended practices are not repeatable enough to serve as the basis for a Federal motor vehicle safety standard. Our conclusion is that attempts to characterize and rate replacement linings have not been completely successful.

The recommendations in the report by ORNL for the near-term could be accepted voluntarily by the industry and the users. Other longer-term research would be questionable with regard to its potential for meaningful and repeatable results. Our conclusion is that NHTSA should not pursue the longer-term, higher-risk research recommendations of ORNL.

Attachment: ORNL Report

DOT HS 809 961
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