TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

IDEA *Innovations Deserving Exploratory Analysis Program*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Emerging Concepts and Products for Highway Systems

Annual Progress Report 1

[illegible]er 1994

NCHRP-IDEA Program
Transportation Research Board
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Telephone 202-334-3568
Fax 202-334-3471

This material is based on work sponsored by the Federal Highway Administration and the American Association of State Highway and Transportation Officials under Cooperative Agreement DTFH61-92-C-00002. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and the IDEA program and do not necessarily reflect the view of the sponsors.

32055745

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAM

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM (NCHRP)

EMERGING CONCEPTS AND PRODUCTS FOR HIGHWAY SYSTEMS

NCHRP-IDEA
ANNUAL PROGRESS REPORT 1

DECEMBER 1994

IDEA PROGRAM

TRANSPORTATION RESEARCH BOARD/NATIONAL RESEARCH COUNCIL

NCHRP-IDEA PROJECT COMMITTEE

Earl C. Shirley, Chairman
Consulting Engineer, California

William Agnew
Director of Research, General Motors (retired)

Robert Gubala
Consultant, Connecticut

Delon Hampton
Delon Hampton & Associates, Chartered

Gary Hoffman
Pennsylvania Department of Transportation

Louis Papet
Federal Highway Administration

Thomas Pasko
Federal Highway Administration

Eugene Reilly
Consultant, New Jersey

Arunoprakash Shirole
New York State Department of Transportation

Lawrence Smith
Florida Department of Transportation

James Taylor
University of Notre Dame

Jon Underwood
Texas Department of Transportation

NCHRP-IDEA Project Support
Frank McCullagh, *Senior Program Officer*

TRB Technical Support
Robert E. Skinner, Jr., *Executive Director*
Robert J. Reilly, *Director, Cooperative Research Programs*
Neil F. Hawks, *Director, Special Programs*
Robert E. Spicher, *Director, Technical Activities*
Stephen R. Godwin, *Director, Studies and Information Services*
Marcia A. Appel, *Director, Administration and Finance*

DOT/FHWA Technical Support
Thomas Pasko, *Federal Highway Administration*
Lou Colucci, *Federal Highway Administration*
Charles Niessner, *Federal Highway Administration*

PREFACE

This annual report presents a summary of progress on investigations conducted as part of the Innovations Deserving Exploratory Analysis (IDEA) program for the National Cooperative Highway Research Program (NCHRP). The NCHRP-IDEA project is jointly funded by the Federal Highway Administration and state highway agencies in cooperation with the American Association of State Highway and Transportation Officials.

NCHRP-IDEA nurtures new technologies, methods, and processes for application to highway systems in broad technical areas such as highway design and construction, materials, operations, and maintenance. The project is patterned after a similar and highly successful IDEA program completed for the Strategic Highway Research Program (SHRP). A seamless transition was made from SHRP-IDEA to the broader NCHRP-IDEA project. NCHRP-IDEA also continues some of the IDEA investigations that did not have an opportunity to be completed within SHRP's time frame.

NCHRP-IDEA is one of the three IDEA program areas managed by TRB for fostering innovations in highway and intermodal surface transportation systems. The other two IDEA program areas are TRANSIT-IDEA, which focuses on products and results for transit practice, in support of the Transit Cooperative Research Program (TCRP), and IVHS-IDEA, which focuses on products and results for the development and deployment of intelligent transportation systems (ITS), in support of the U.S. Department of Transportation's national ITS program plan. The three IDEA program areas are integrated to achieve the development and testing of nontraditional and innovative concepts, methods, and technologies, including conversion technologies the defense, aerospace, computer, and communication sectors that are new to highway, transit, intelligent, and intermodal surface transportation systems. The report includes a summary list of all IDEA awards and emerging products in IDEA programs managed by TRB.

The NCHRP-IDEA investigations presented in this report were chosen after technical review by a panel of technical experts and evaluation and approval by the NCHRP-IDEA Project Committee. A list of technical experts appointed by TRB to serve on NCHRP-IDEA technical expert panels and a list of the members of the NCHRP-IDEA Project Committee are included in the progress report. The investigations in the report are presented in the order in which they were awarded.

IDEA project costs range from a low of about $30,000 to a high of about $100,000, depending on the investigative needs and testing requirements of each project. Most NCHRP-IDEA investigations are designed to be completed within about a year.

Because of the technical complexity of some of the IDEA investigations and potential significance of results to highway practitioners, a national expert is selected to serve as a voluntary technical advisor to one or more of the IDEA investigations. The technical advisor provides advice and counsel on specific IDEA investigations and assists in heightening the exposure of the investigators and IDEA results to highway practitioners.

The success of the NCHRP-IDEA program relies heavily on the effectiveness with which IDEA products and results are made available to highway practitioners. The annual progress report is a first step in providing highway practitioners the background and summary details on each IDEA investigation and forthcoming products.

The IDEA program welcomes your comments, suggestions, and recommendations on emerging IDEA products presented in this report. Please contact Dr. K. Thirumalai, IDEA Program Manager, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

NCHRP-IDEA TECHNICAL EXPERT PANEL MEMBERS[1]

Gifford Albright
Pennsylvania State University

Thomas Atkinson
Wyoming Highway Department

David Beal
New York Department of Transportation

Greg Bobrowski
Research Master Builders

James Brown
Consultant, Texas

John Carney
Vanderbilt University

Gary Demich
Washington State Department of Transportation

Denis Donnelly
Consultant, Colorado

Conrad Dudek
Texas A&M University

Geoffrey Frohnsdorff
National Institute of Standards and Technology

Tony Garcia
DRC Consultants

Robert Girard
Missouri Department of Transportation

Neil Hawkins
University of Illinois at Urbana-Champaign

Anne Hiltner
Case Western Reserve University

Albert Kobayashi
University of Washington

Marty Laylor
Oregon Department of Transportation

D. Y. Lee
Iowa State University

Vernon Marks
Iowa Department of Transportation

Bryant Mather
U.S. Army Corps of Engineers Waterways Experiment Station

Rebecca McDaniel
Indiana Department of Transportation

William McLeese
U.S. Army Corps of Engineers Waterways Experiment Station

Sue McNeil
Carnegie Mellon University

Brian McWaters
Iowa Department of Transportation

Gerald Miner
Consultant, Missouri

Raymond Moore
University of Kansas

Tapan Mukherjee
National Science Foundation

Howard Newlon, Jr.
Consultant, Virginia

Richard Parker
Oregon Department of Transportation

Rodney Pletan
Minnesota Department of Transportation

V. Ramakrishnan
South Dakota School of Mines

Richard Rogers
Texas Department of Transportation

Charles Scholer
Purdue University

Lawrence Scofield
Arizona Department of Transportation

C. William Smith
Virginia Polytechnic Institute

Stella White
Saskatchewan Highways and Transportation

Thomas Zimmie
Rensselaer Polytechnic Institute

[1]IDEA expert panel members are appointed by the Transportation Research Board for evaluating IDEA proposals and technical program areas for NCHRP-IDEA. The number and composition of panels selected for evaluating IDEA proposals vary based on the technical mix of the proposals. Additional members will be nominated to the current pool of experts during the second program year.

TABLE OF CONTENTS

Summary List of NCHRP-IDEA Awards in Broad Technical Areas

I. Maintenance, Repair, and Rehabilitation of Highway Systems

IDEA Project

3 *Development of Guidelines for Low-Cost Sprayed Zinc Galvanic Anode for Control of Corrosion of Reinforcing Steel in Marine Bridge Substructures*
University of South Florida, Tampa
Florida Department of Transportation

7 *Strategy for Coating Structural Steel Without Stringent Blasting Regulations*
Steel Structures Painting Council, Pittsburgh, Pennsylvania

11 *Rehabilitation of Steel Bridges Through Application of Advanced Composite Materials*
University of Delaware, Newark
Lehigh University, Bethlehem, Pennsylvania

16 *Laser Removal of Paint on Pavement*
MOXTEX Incorporated, Orem, Utah

18 *Development of New Principles of Design of Tools for Repair and Removal of Pavements Based on the Effect of Lateral Propagation of Cracks Under Contact Loading*
POTOK Centre, Kiev, Ukraine

II. Pavement Management

IDEA Project

12 *Advanced Testing of an Automatic Non-Destructive Evaluation System for Highway Pavement Surface Condition Assessment*
Illinois Institute of Technology, Chicago

III. Traffic Operations and Safety

IDEA Project

8 *Conservation Traffic Control Load Switch*
CLS Incorporated, Westerville, Ohio

15 *A Road Crew Portable Laser Warning System Concept Development and Demonstration*
Loral, Manassas, Virginia

IV. Advanced Design of Highway Structures

IDEA Project

14 *Unreinforced, Centrally Prestressed Concrete Columns and Piles*
Florida Atlantic University, Boca Raton

V. Technologies for Quality Control for Pavement Construction and Condition Assessment

IDEA Project

1 *On-Line Real-Time Measurement and Control of Aggregate Gradation in Asphalt Plants*
Felix ALBA Consultants Incorporated, Murray, Utah

2 *Development of a Method for Measuring Water-Stripping Resistance of Asphalt/Siliceous Aggregate Mixtures*
National Institute of Standards and Technology, Gaithersburg, Maryland

5 *Magnetic Resonance for In Situ Determination of Asphalt Aging and Moisture Content*
Southwest Research Institute, San Antonio, Texas

17 *Development of a Self-Contained Portable Device for SHRP Binder Testing: Field QC/QA Testing with the Duomorph*
University of Illinois, Urbana-Champaign

VI. High-Performance Pavement Materials and Systems

IDEA Project

4 *Exploring the Feasibility of Replacing Latex with Asphalt Emulsion for Use in Bridge Deck Overlays*
Purdue University, West Lafayette, Indiana

6 *Excogitated Composite Multifunctional Layer for Pavement Systems*
University of Illinois, Urbana-Champaign

13 *New Additive for Improved Durability of Concrete and Prevention of Reinforcing Corrosion*
University of Connecticut, Storrs
Todd Chemical, Cheshire, Connecticut

VII. Rebar Corrosion Resistance

IDEA Project

9 *Corrosion-Resistant Steel Reinforcing Bars*
University of Kansas, Lawrence

10 *Metallic Coating for Corrosion Protection of Steel Rebars*
SRI International, Menlo Park, California

Summary List of TRANSIT-IDEA Awards and Emerging Products

Transit-IDEA Awards	Emerging Product
Baylor College *Wheelchair Restraint System* Thomas Krouskop, Principal Investigator	Designs and tests a wheelchair restraint system for improved safety and mobility of the handicapped.
San Francisco Bay Area Rapid Transit District *Adaptive Diagnostic System Project* Steven Mullerheim, Principal Investigator	Develops an automated general purpose tester with artificial intelligence capabilities for transit equipment units.
International Electronic Machines *Automatic Wheel Inspection Station* Zahid Mian, Principal Investigator	Demonstrates the feasibility of an automatic wheel inspection system for rail vehicles that uses laser scanning technology.
Tri-County Metropolitan District of Oregon *Customer Satisfaction Index for the Mass Transit Industry* Kathryn Coffel, Principal Investigator	Develops a common measurement or "yardstick" to determine customer satisfaction with mass transit and monitor progress over time.
Northeastern University *Management Information Benefits of Integrating Electronic Fareboxes with Other On-Board Equipment* Peter Furth, Principal Investigator	Evaluates the benefits of integrating farebox information with other on-board equipment to provide passenger information for transit monitoring and planning.
Georgia Institute of Technology *Improved Passenger Counter and Classifier System for Transit Applications* E. F. Greneker, Principal Investigator	Evaluates a novel floor mat sensor technology for a combined transit passenger counter and rider information system.
Transit Engineering *Interactive Training with Video and Audio* Jim McDowell, Principal Investigator	Demonstrates an interactive transit operator training system using video image storage and display.
Transcom International Ltd. *Real-Time Transit Data Broadcast* Edward Burgener, Principal Investigator	Develops and tests transit broadcast software and a personal portable receiver that will provide passengers with real-time transit status information.

Summary List of IVHS-IDEA Awards and Emerging Products

IVHS-IDEA Awards	Emerging Product
University of Michigan *Collision Avoidance and Improved Traffic Flow Using Vehicle-to-Vehicle Communication* Bernard Galler, Principal Investigator	Evaluates vehicle-to-vehicle communication requirements to support collision avoidance and improved traffic flow.
Purdue University *Models for Real-Time Incident Prediction* S. Madanat, Principal Investigator	Develops and designs a system for anticipating highway incidents from traffic and environmental data that will support proactive response measures.
C. F. International *Improved Metropolitan Area Transportation System (IMATS); Carpooling and Computerized Vehicle Dispatching in Association with a Vehicle Rental System* John Chisholm, Principal Investigator	Evaluates computerized dispatching of car-pool vehicles and provision of short-term rental vehicles to improve metropolitan area transportation systems.
Louisiana State University *A Distributed Input/Output Subsystem for Traffic Signal Control* Darcy Bullock, Principal Investigator	Evaluates a distributed input/output subsystem concept for electronically controlling traffic signals that significantly reduces wiring complexity.
Auburn University *Feasibility Study of IVHS Drifting Out of Lane Alert System* Ed Ramey, Principal Investigator	Evaluates technical viability of sensing the painted strips on highways as a basis for an IVHS lane departure alert system.
Schwartz Electro-Optics, Inc. *Laser-Based Vehicle Detector/Classifier* Richard Wangler, Principal Investigator	Designs and tests a laser imaging system that can detect and classify highway vehicles in real time.
Honeywell Technology Center *Driver-Adaptive Warning System* Chris Miller, Principal Investigator	Develops and tests a hybrid learning system algorithm that assesses patterns of individual driving behavior and sets driver warning thresholds for lane-keeping and related maneuvers.
SUNY at Stony Brook *Laser Optics Open-Air Communication System* Sheldon Chang, Principal Investigator	Evaluates an open-air laser optics communication system concept for highway-vehicle communications and for sensing vehicle position within highway lanes.
University of Michigan *Decision-Theoretic Reasoning for Traffic Monitoring and Vehicle Control* Michael Wellman, Principal Investigator	Evaluates a new concept for IVHS decision-making, based on theoretic reasoning theory, for traffic monitoring and vehicle control.
SRI International *Scale-Model AHS Research Facility (SMARF)* Raul Vera, Principal Investigator	Develops and tests a scale model facility for cost-effective evaluation of new IVHS vehicle control concepts.

Compuline, Inc. *Vehicle Lane Control System* Bill Bush, Principal Investigator	Develops and tests an automated lane control system based on vehicular sensing of resonant "tank circuits" located on the roadway surface.
University of Washington *Development of an Intelligent Air Brake Warning System for Commercial Vehicles* Per Reinhall, Principal Investigator	Evaluates an on-board real-time brake performance monitoring and warning system concept.
Christian Brothers University *Adaptive Filtering for IVHS and Advanced Vehicle Control* Laura Ray, Principal Investigator	Applies tire force signals to achieve real-time feedback to improve control system performance for automated highway system vehicles.
Purdue University *Efficient Use of Narrowband Radio Channels for Mobile Digital Communications* Michael Fitz, Principal Investigator	Develops a bandwidth efficient highway communication architecture for IVHS using advanced modulation and coding techniques.
University of California-Berkeley *Engineered Visibility Warning Signals: Tests of Time To React, Detectability, Identifiability, and Salience* Ted Cohn, Principal Investigator	Applies human factors principles to improve the readability of on-board display systems and warning signals.
Purdue University *A Sequential Hypothesis Testing-Based Decision-Making System for Freeway Incident Response* S. Madanat, Principal Investigator	Develops a dynamic, cost-based, decision-making system that can support highway incident response management.
Northrop Corporation *Three-in-One Vehicle Operator Sensor* Sam Puma, Principal Investigator	Develops an integrated system that can monitor driver identity and impairment due to drowsiness or intoxication b analysis of images from a video sensor.
The Analytic Sciences Corporation (TASC) *AutoAlert: Automated Acoustic Detection of Traffic Incidents* Dave Whitney, Principal Investigator	Evaluates a direct incident detection and alert system that identifies dynamic traffic characteristics by analysis of acoustic patterns.
National-Louis University *Real-Time, Computer-Matched Ridesharing Using Cellular or Personal Communications Services (RTCMR/C/PCS)* Ed Walbridge, Principal Investigator	Develops and tests a personalized ridesharing system that uses cellular phones or other personal communication services (PCS) to achieve quick-response ride matching.
Northrop Corporation *Interference-Resistant Signals for Collision Avoidance Radar* Mark Hischke, Principal Investigator	Develops and tests an advanced spread spectrum radar signal processing system that can significantly reduce false alarms and blindings in a congested IVHS environment.

ON-LINE REAL-TIME MEASUREMENT AND CONTROL OF AGGREGATE GRADATION IN ASPHALT PLANTS

NCHRP-IDEA Project 1[1]

Felix Alba, Felix ALBA Consultants Incorporated, Murray, Utah
Mike Worischeck and Steve Madrigal, STAKER Paving and Construction, Salt Lake City, Utah

IDEA PRODUCT

The size distribution (gradation) of aggregates coming out of belt feeders is measured, on-line and in real-time (every 5 minutes). On the basis of these size measurements, and the job mix formula, the optimal proportioning factors for each of the bins are calculated, so as to dynamically adjust the speed of their belt feeders.

A prototype system was successfully tested. This IDEA technology has the potential to deliver asphalt aggregates continuously that comply with the job mix formula and to do so with a more uniform flow (fewer dead periods). This procedure will optimize asphalt and aggregates, enhancing the quality of pavement construction.

The quality of asphalt pavement construction highly depends on the size distribution of the aggregates in the final mixture. In a typical asphalt plant, the job mix formula being sent into the mixer is obtained by properly proportioning aggregates with different controlled gradations coming out of four or more bins. These proportioning factors are calculated off-line on the basis of average values for the gradations in each of the stockpiles from which the different bins are loaded.

CONCEPT AND INNOVATION

This IDEA product is based on the principles of machine vision, image processing, stereology, and deconvolution mathematics. Figure 1 schematically shows the measurement and control concept. It starts with a lamp (L) and line-scan video camera (C) at each one of the belt feeders (BF) associated with each one of the cold bins (CB).

The raw images of the aggregates falling to the master belt (MB) are gathered by frame grabbers (FG) and preprocessed by image processor (IP) boards connected to the data bus of a host computer (HC). Additional image processing and particle recognition algorithms executed in the HC determine the chord-length distribution of the aggregates. The chord-length distribution is transformed into volumetric (sieve) size gradation by numerically inverting a mathematical stereological model that relates the monodimensional information to the tridimensional one.

Finally, using optimization algorithms, the HC calculates in real-time the optimal proportioning factors for each bin to comply with the job mix formula. Belt feeder speeds are adjusted accordingly.

IDEA PROJECT INVESTIGATION AND PROGRESS

An initial IDEA concept feasibility project was completed under the Strategic Highway Research Program (SHRP). The project determined the feasibility of the concept in a laboratory prototype setup (*1,2*). This IDEA project is a continuation of that SHRP project and was started in September 1992 to design and test a full-scale prototype at Staker Plant in Salt Lake City, Utah (*3*).

The IDEA project was performed in three stages. Stage 1 consisted of undertaking the underground installation for all power and video signals from the bins to the computer room, design and construction of the camera housing, and design and construction of the electronic interface between the line-scan camera and the image frame-grabber inside the computer (*4*).

Stage 2 included the testing of all hardware, development of a suitable software structure to conduct all necessary experimental work, and intensive software development for image processing and particle recognition, so practical problems encountered in a full-scale operation (e.g., variable belt feeder speed, rock

[1]This IDEA project is a continuation of a SHRP-IDEA project and will be completed by January 1995.

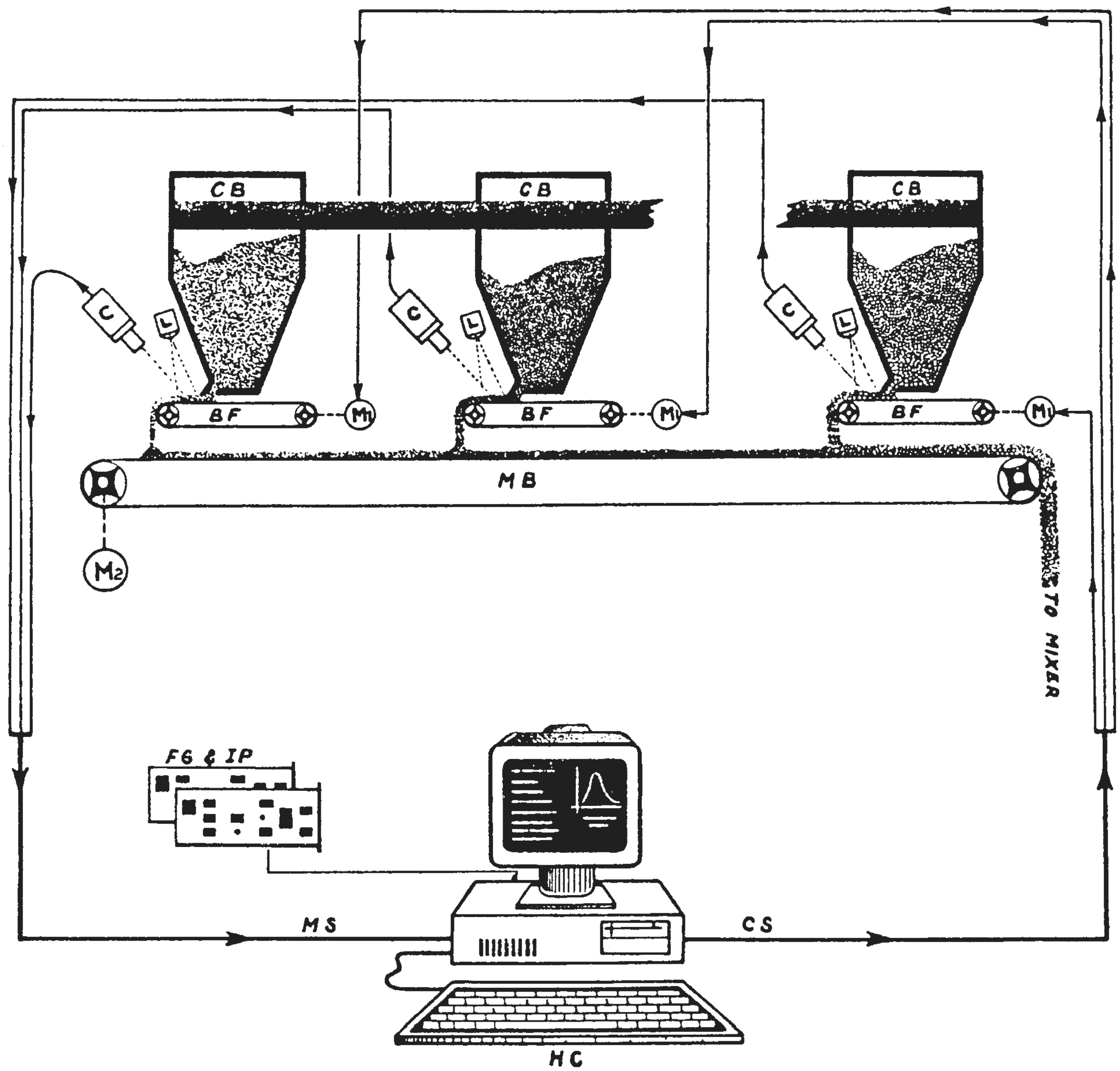


FIGURE 1 Concept for aggregate gradation control technology.

humidity, etc.), but not in the laboratory prototype experiments, could be effectively solved. All image preprocessing was programmed in the C language, numerical routines in FORTRAN 77, and the operator interface in Visual Basic for MS-DOS (*5*).

During Stage 3, the necessary software for closing the control loop was developed, i.e., progressing from the gradation measurement to the determination of the optimal proportioning factors, and finally to the actuation of the belt feeders. In this final stage, the performance of the instrument in both aspects is being evaluated: its reproducibility and accuracy as compared with standard sieve analysis, and its effectiveness in recommending the proper proportioning factors.

Prototype Description

A Pulnix line-scan camera with 5,000 pixels/line was employed with the EPIX 4meg video frame-grabber. An ad-hoc interface between the frame-grabber and the camera was developed jointly with EPIX, Inc. For the coarse materials (3/4-inch, 1/2-inch, 3/8-inch) a non-expensive Pentax A50mmF2 lens was attached to the camera, providing a transversal resolution of about

50μm/pixel. For the 1/8-inch sand material, a macro-lens Pentax FA100mmF2.8 was used that provided a transversal resolution of 7μm/pixel. Longitudinal resolution depends on the integration time of the camera (500μs) and the speed of the belt feeders. It oscillates typically between 30μm/line and 70μm/line.

Figure 2 shows the camera housing plus illumination installed on the bin structure. The camera is refrigerated with compressed air. This air also provides a slightly higher interior pressure to seal the housing from dust and, on its way out of the chamber, is redirected, blowing flush to the lens window to minimize the deposition of dust on the glass. An electronic air drier and purifier is employed to protect the camera from water and oil in the air line.

Figure 3 displays the computer system, which is composed of a 486/50 computer, 330MB of hard disk, 5.25-inch and 3.5-inch floppy disk drives, removable Bernoulli 90MB disk drive for off-line image storage, VGA color monitor, printer, and a video monitor to visually inspect the images. The system is connected through an RS-232 communication link to the Seltec computer upstairs in the control room.

Experimental Results

A problem initially encountered with the measurement of coarse aggregates was the inability of the instrument to accurately estimate a low percentage (about 3% to 5%) of material under the mesh #200 that existed as a film of dust attached to the particles. This dust did not exist if the processed aggregate had been previously washed. This deficiency is inherent to the technology. If the camera is focused to see the rocks, it cannot see the dust, and vice versa.

FIGURE 2 Camera housing plus illumination on bin structure.

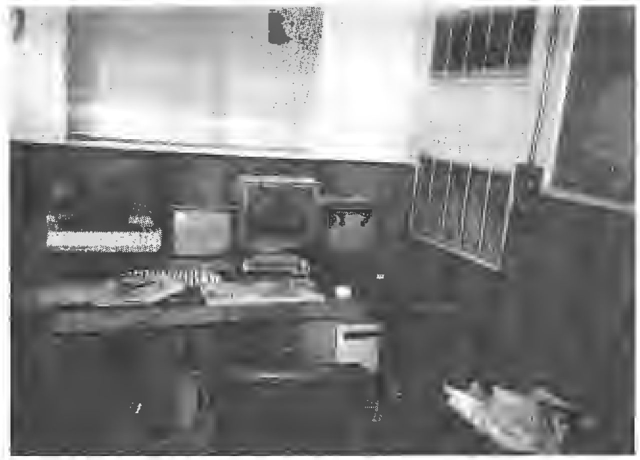


FIGURE 3 Computer system setup.

Even though neglecting this low percentage of dust does not significantly affect the control of the plant (typically a plant mix has only about 10% below #200 and comes primarily from the sand bins), a semi-empirical technique to account for this deficiency was developed. Because the global light reflectivity of the aggregate changes significantly whether it is washed or not, and that change reflects on thestatistical pattern of the signals, the instrument detects that wet/dry condition and, if the aggregate is not washed, adds a constant percentage of about 4% to the fraction under #200. This simple technique helped to improve the accuracy with which the instrument determined the optimal proportioning factors to minimize deviations from the job mix formula.

After long periods of continuous operation, for the coarse aggregates (3/4-inch, 1/2-inch, 3/8-inch), the prototype demonstrated that it can measure the gradation with a reproducibility better than 2% absolute on each mesh and with an accuracy (relative to standard sieving) better than 4% absolute on each mesh. Tables 1 and 2 show two screens of the instrument, one about 20 minutes after the other when monitoring the 1/2-inch bin. Table 1 demonstrates that the prototype was able to detect a significant deviation from the average distribution, due to a new loader operator who was scooping too low from the stockpile and adding too much fines to the fractions under 3/8 inch and #4. It took about 20 minutes to identify the cause of the problem and correct it, as demonstrated by the instrument screen in Table 2.

Currently the prototype is installed on the 1/8-inch sand bin. This aggregate typically has an aggregate size distribution with about 98% under #4, 70% under #8,

TABLE 1 On-Line Aggregate Size Distribution Analyzer Based on Computer Vision — Measurement of Sieve Size Distribution

Mesh	Staker (%	Ocusizer (%	Abs. Dev. (%
1-inch	100.0	100.0	0.0
3/4-inch	100.0	100.0	0.0
1/2-inch	100.0	99.7	-0.2
3/8-inch	75.0	88.7	13.7
#4	4.2	12.7	8.5
#8	3.2	3.8	0.6
#16	2.8	3.4	0.6
#30	2.7	3.4	0.7
#50	2.7	3.4	0.7
#100	2.5	3.3	0.8
#200	2.3	2.3	0.0

TABLE 2 On-Line Aggregate Size Distribution Analyzer Based on Computer Vision — Measurement of Sieve Size Distribution, 20 Minutes Later

Mesh	Staker (%	Ocusizer (%	Abs. Dev. (%
1-inch	100.0	100.0	0.0
3/4-inch	100.0	100.0	0.0
1/2-inch	100.0	99.9	-0.0
3/8-inch	75.0	82.1	7.1
#4	4.2	4.5	0.3
#8	3.2	3.3	0.1
#16	2.8	3.3	0.5
#30	2.7	3.3	0.6
#50	2.7	3.3	0.6
#100	2.5	3.3	0.8
#200	2.3	2.2	-0.0

40% under #16, 12% under #50, and about 2% under #200. In attempting to mathematically characterize the size distribution obtained by sieving, it is found that these aggregates possess bimodal gradations: a fine mode with a mean of about 0.4mm and a coarse mode with a mean of about 2.5mm, with the latter amounting to about 70% of the distribution.

The macro-lens with a focal length of 100mm used for this bin provides enough resolution (7μm/pixel to discriminate the dust. Our instrument typically reported that about 10% by number (0.33% by length) of the measured chord-lengths were under 60μm. However, according to the stereological model, the expected percentage by length under 60μm should be much larger (about 3% to 5%). The conclusion is that even though the technology has the capability of discriminating the dust, due to the high humidity of this type of aggregate, particles agglomerate considerably causing the instrument to underreport the fines. This is a clear limitation of the technology, as the camera cannot see the totality of the primary particles that, instead, are reported in conventional sieving after washing.

In spite of this limitation, a technique based on empirical knowledge gathered over the years by the asphalt industry regarding the functional structure of these distributions was devised. The technique consists of the instrument (a) using only about 70% of the basic measured chord-length distribution, discarding the fines tail, which is known to lack accuracy; (b) inverting the stereological model as usual but considering the resulting volume distribution only as the coarse mode of the final result; and (c) adding to that coarse mode a fine mode that conforms to the typical contents of fines of the aggregates and linking smoothly with the coarse mode. This technique is in essence equivalent to extrapolating the missing 30% of the distribution from the measured 70%, but it has been proved to be more consistent and accurate.

In conclusion, even though agglomeration of humid very fine aggregates impairs the accuracy of the instrument on the fines tail of the distribution, a combination of partial measurement of the coarse mode with a technique similar to extrapolation made it possible to obtain accurate measurements of the sieve size distribution on the 1/8-inch sand bin and determine the optimal proportioning factors for all bins.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The IDEA technology has been proved to be a reliable and accurate tool for the on-line real-time measurement and control of the gradation in drum-mix plants. Limitations have been identified and semi-empirical solutions successfully tested. Different aggregates have been tested from 3/4-inch, 1/2-inch and 3/8-inch rock through 1/8-inch sand by installing the same hardware in the corresponding bins. The next step is to design the first commercial prototype capable of monitoring all bins simultaneously so global control of the plant can be achieved. Some instrumentation companies are already interested in pursuing the commercialization, and preliminary negotiations are taking place. The IDEA program expects a commercial model tc be developed by a user-supported project.

REFERENCES

1. F. Alba. *Development of a Prototype for On-Line Real-Time Measurement and Control of Aggregate Gradation in Asphalt Plants*, Phase I. Stage 1 Progress Report to SHRP-IDEA. Felix ALBA Consultants, Inc., Aug. 1992.

2. F. Alba. *Development of a Prototype for On-Line Real-Time Measurement and Control of Aggregate Gradation in Asphalt Plants*, Phase I. Stage 2 Progress Report to SHRP-IDEA. Felix ALBA Consultants, Inc., Feb. 1992.

3. F. Alba. *Development of a Full-Scale Prototype for On-Line Real-Time Measurement and Control of Aggregate Gradation in Asphalt Plants*, Phase II. Proposal to SHRP-IDEA. Felix ALBA Consultants, Inc., April 1992.

4. F. Alba. *Development of a Full-Scale Prototype for On-Line Real-Time Measurement and Control of Aggregate Gradation in Asphalt Plants*, Phase II. Stage 1 Report to NCHRP-IDEA. Felix ALBA Consultants, Inc., Feb. 1993.

5. F. Alba. *Development of a Full-Scale Prototype for On-Line Real-Time Measurement and Control of Aggregate Gradation in Asphalt Plants*, Phase II. Stage 2 Report to NCHRP-IDEA. Felix ALBA Consultants, Inc., Sep. 1993.

DEVELOPMENT OF A METHOD FOR MEASURING WATER-STRIPPING RESISTANCE OF ASPHALT/SILICEOUS AGGREGATE MIXTURES

NCHRP-IDEA Project 2[1]

Tinh Nguyen, Eric Byrd, and Jim Seiler
National Institute of Standards and Technology, Gaithersburg, Maryland

IDEA PRODUCT

Specific techniques have been developed to determine both the thickness of the interfacial water layer and adhesion loss. The first technique, measuring water at the asphalt/aggregate interface, is a non-destructive technique based on Fourier transform infrared spectroscopy in the multiple internal reflection mode (FTIR-MIR). In this technique, water reaching the asphalt/siliceous aggregate interface is detected by the evanescent wave that was produced by the total internal reflection of the infrared radiation. FTIR-MIR offers a number of advantages for measuring water at the asphalt/aggregate interface because (a) it is sensitive to water molecules; (b) it can be used at ambient conditions, and thus, is suitable for in-situ study; (c) it detects water from the substrate side, thereby avoiding interference of water from the air; and (d) it can provide quantitative information on the water layer at the interface. If a correlation is established between the water layer thickness and the adhesion loss due to water exposure, this technique could provide information on the stripping of asphalt at the molecular level.

The second technique relies on the use of a pneumatic pull-off adhesion tester in conjunction with a porous stub that allows water to migrate through the asphalt film to the asphalt/aggregate interface. This test was initially developed to verify the adhesion loss/water layer thickness relation. However, because of its ease of use, reproducibility, and portability, this test can be used to rapidly test the water-stripping resistance of an asphalt on an aggregate in the field as well as in the laboratory.

CONCEPT AND INNOVATION

The concept is based on a method to measure the water-stripping resistance and water susceptibility of asphalt/siliceous aggregate mixtures, asphalt binders, and aggregates. Water at the interface has been established as the main cause of stripping of an asphalt from a siliceous aggregate. The loss of asphalt/aggregate bond strength (adhesion) in the presence of water or high relative humidities is believed to be due to the buildup of the water layer at the asphalt/aggregate interface. Measuring either the thickness of the interfacial water layer or the adhesion loss of the asphalt/aggregate mixture as a function of exposure to water provides a practical means for assessing the stripping resistance of an asphalt on an aggregate.

IDEA PROJECT INVESTIGATION AND PROGRESS

The IDEA project has developed techniques for measuring water-stripping resistance of an asphalt on a siliceous aggregate. The results of these developments are summarized below.

Measurement of Thickness of Water Layer at Asphalt/Siliceous Aggregate Interface

Figure 1 presents the experimental setup used to measure the thickness of the water layer at the interface between an asphalt and a siliceous substrate by the FTIR-MIR technique. Specimens for this measurement were prepared by applying hot asphalt (at 60°C) to one surface of the substrate. The siliceous substrate was a SiO_2-covered silicon prism. At ambient conditions, the surfaces of this substrate should be covered with silanol (SiOH) groups and adsorbed water, similar to the functional groups on a siliceous aggregate surface. A water chamber was attached to each asphalt-coated specimen. The specimen with the water chamber attached was positioned vertically in an accessory holder. After water was added to the chamber and the specimen assembly was placed in the spectrometer, FTIR-MIR spectra were taken automatically every 15 minutes without disturbance to the instrument until the experiment was complete. With the configuration shown in Figure 1, the only

[1]This IDEA project is a continuation of a SHRP-IDEA project and will be completed by January 1995.

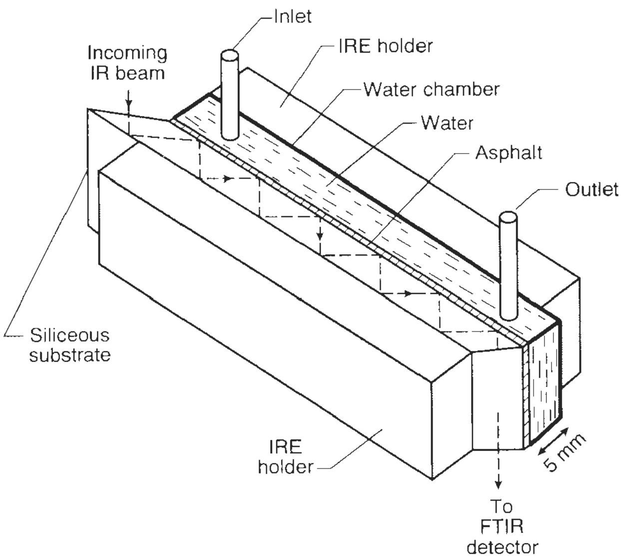


FIGURE 1 Experimental setup for measurement of water at asphalt/substrate.

pathway for water migration from the environment to the asphalt/substrate interface is through the thickness of the asphalt film within the walls of the chamber.

Figure 2a shows typical unprocessed FTIR-MIR spectra for an asphalt-coated specimen before and after exposure to water for different times. The thickness of the asphalt film was about 60 μm. Although the effects of water are evident in the 3000-3650 and 1625-1645 cm^{-1} regions, these spectra still contain information of the asphalt material. To provide data for quantitative analysis of water at the asphalt/siliceous aggregate interface, difference spectra were acquired by subtracting the spectrum collected before exposure from those obtained at different water exposure times. Figure 2b presents difference spectra in the 2800-3800 cm^{-1} region (strongest water absorbance region) for an asphalt on a SiO_2-covered Si substrate exposed to distilled water for different times. If water has no effect, all difference spectra would be straight lines with the exception of the intensity fluctuations of the CO_2 bands from the air in the spectrometer. Bands above or below the baseline of a difference spectrum indicate an increase or a decrease, respectively, of the concentration of a chemical functional group as a result of water exposure.

Figure 2b clearly shows that the intensity of the water band in the 3000-3650 cm^{-1} region increased while the intensity of the asphalt bands (e.g., at 2922 cm^{-1}) decreased with time of exposure to water. These changes are the result of water entering the asphalt/substrate interface and pushing the asphalt film away from the substrate. The band at 3400 cm^{-1} is due to the OH stretching of water. The intensity, expressed as peak height, of this band is suitable for determining the thickness and amount of water at the asphalt/substrate interface. The absorbance intensity at each exposure time displayed in Figure 2b represents the total amount of water detected. This water comprised water at the coating/substrate interface and water in the asphalt film within the depth of the evanescent wave (<0.3 μm). Substracting the water uptake within the evanescent wave depth in the asphalt from the total water detected yields the values on water at the asphalt/substrate interface. Extensive analysis has shown that for hydrophobic organic materials such as asphalt, water detected is mainly from the water layer at the film/substrate interface.

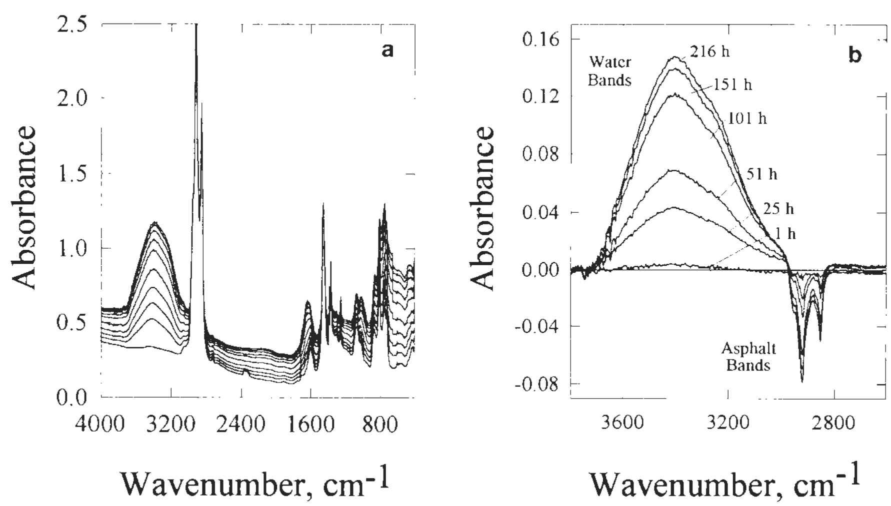


FIGURE 2 Typical unprocessed (a) and difference FTIR-MIR spectra (b) for several exposure times of asphalt/siliceous substrate specimen to water.

The thickness of the water layer, l, at the asphalt/siliceous substrate interface was determined using the following expression:

$$l = \frac{d_{pw}}{2}\left[-\ln \frac{1-\frac{A}{A_\infty}}{1-c_w \frac{d_{pc}}{d_{pw}}} \right]$$

where A is the FTIR-MIR absorbance (obtained from Figure 2a); A_∞ is the maximum infrared absorbance of water (provided by FTIR-MIR analysis of water on an asphalt-free substrate); c_w is the fraction of water sorbed in the asphalt within the evanescent depth (extrapolated from water uptake in asphalt); and d_{pw} and d_{pc} are the penetration depths of the evanescent wave in water and asphalts, respectively (calculated from penetration depth equation). For a silicon substrate d_{pw} = 0.22 μm and d_{pc} = 0.24 μm. This equation was derived using the two-layered model (water at the interface and water sorbed in the penetration depth of the evanescent wave) and the internal reflection theory. It is still valid for the case in which the water layer at the asphalt/substrate interface is not continuous, e.g., discrete droplets.

Assuming that water is distributed uniformly over the entire surface area of the specimen, the amount of water at the asphalt/substrate interface is given by

$$Q_i = la\rho$$

where a is the area in contact with water and is ρ the density of water at the interface.

Figure 3 displays plots of the thickness of the water layer at the asphalt/SiO_2-Si substrate interface as a function of exposure time for three Strategic Highway Research Program (SHRP) asphalts (AAD-1, AAG-1, and AAM-1). It can be seen that for exposures longer than 10 hours, the thickness of the water layer at the interface is greatest for the AAD specimen and smallest for the AAM, suggesting that the AAM is more resistant to stripping than the AAD. Further, at long exposure times, many monolayers of water have accumulated at the asphalt/substrate interface (one monolayer of water is about 0.3 nm thick).

Measuring Adhesion Loss of Asphalt/Aggregate Bond in Water

Figure 4 is a schematic of the instrument used to measure adhesion loss of an asphalt on an aggregate. The main features of this device are a pneumatic adhesion tester, a piston, and a loading fixture consisting of a porous stub attached to a screw. In this study, the porous stubs, 12 mm in diameter and 6 mm thick, were made of brick. The pores in the brick stubs provide increased surface area for adhesive bonding of the asphalt to the stub and also allow water to migrate through asphalt film thickness to the interface. Specimens used for this test were prepared by applying hot

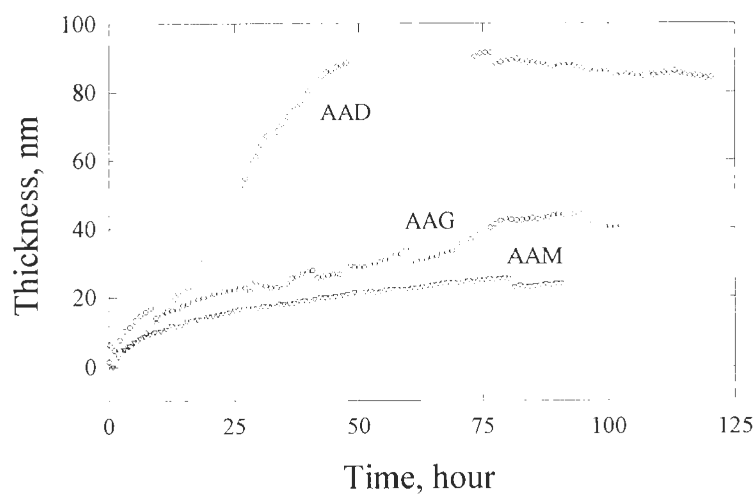


FIGURE 3 Thickness of water layer asphalt/siliceous substrate interface as a function of exposure time in water for AAD, AAG, and AAM asphalts.

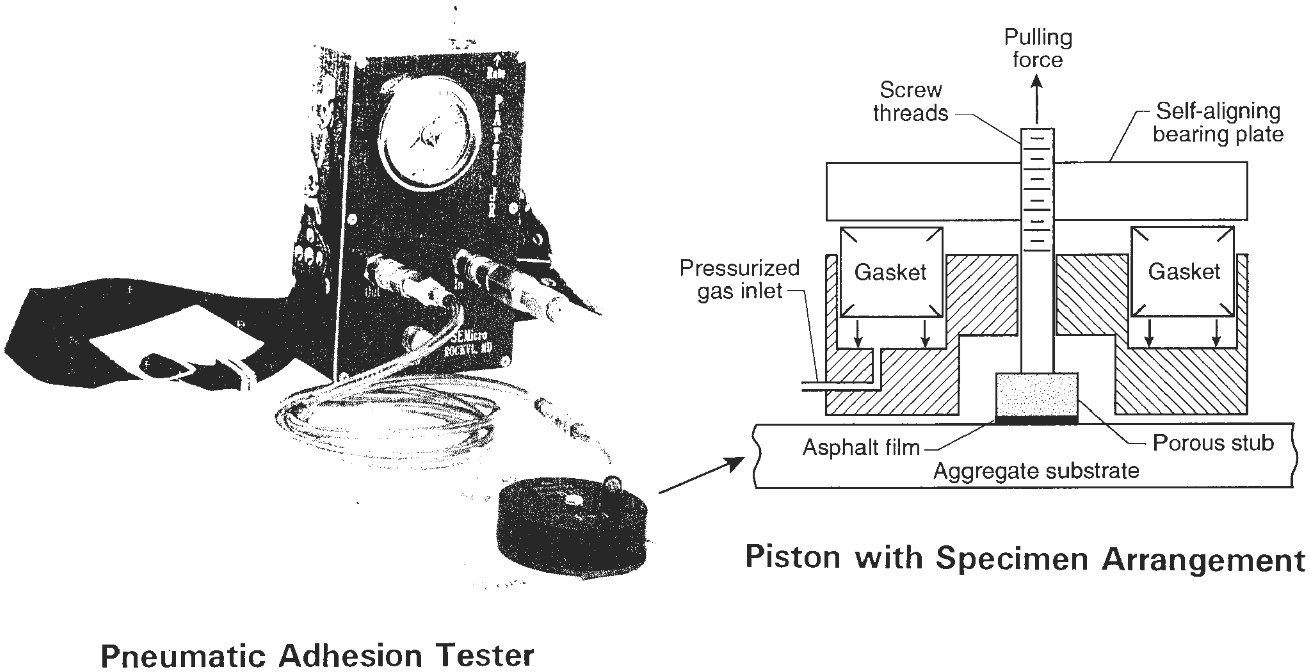


FIGURE 4 Components of apparatus and specimen arrangement used for testing adhesion loss of asphalt on a substance exposed to water.

asphalt to the approximately 12-mm-diameter confined area of the substrate. The substrates used in this study were flat, 200x200x6-mm granite and glass plates. The porous stub-attached screw was pressed on each asphalt-coated area. Excess asphalt around the stub was removed using a razor blade. A small fraction (0.5% based on asphalt weight) of glass beads having desired diameters mixed in the hot asphalt were found convenient for controlling asphalt film thickness.

After conditioning or exposing a specimen to water, the piston is placed over the loading fixture and against the substrate surface. Compressed air is introduced and as air pressure in the piston increases, an airtight seal is formed between the piston gasket and the substrate. When the pressure in the piston exceeds the cohesive strength of the asphalt or the adhesion between the asphalt and the substrate, the specimen breaks, either cohesively in the asphalt or at the asphalt/substrate interface. Pressure at break was recorded and converted into a stress. The results showed that for glass and granite substrates, prior to water exposure, all specimens failed cohesively and that the coefficient of variance (COV) of the bonding strength between specimens was less than 7 percent. This result indicates that this test is suitable for evaluating the cohesive or adhesive strength of an asphalt on a substrate. The COV seemed to be higher when testing specimens that had been immersed in water, particularly when the mode of failure changed from cohesive to adhesive (at the asphalt/substrate interface) or to a mixed mode (adhesive and cohesive). The higher COV after water exposure was probably due to the inhomogeneous nature of the asphaltic materials. This was evidenced by light microscopy results of specimens after the testing, which showed that fractured surfaces consisted of large black areas of unmodified asphalt mixed with small gray areas. The latter was probably formed by the emulsification of water-soluble components in the asphalts. It is noted that this technique could be used for any type of substrate, siliceous or non-siliceous, provided that it is flat enough to provide a tight seal with the gasket.

The loss of the bonding strength of SHRP asphalts on granite and glass substrates exposed to distilled water was evaluated using the technique. The results for three SHRP asphalts having a thickness of 200 μm on a granite substrate are presented in Figure 5 (each data point is the average of six specimens). On a relative basis, the bond strength of the AAD specimen decreased quite fast and within a short exposure time, whereas both the rate of adhesion loss and time to failure were considerably smaller for the AAM specimen. From these results, the AAM appeared to be the most resistant and the AAD the least resistant to stripping on a granite substrate. These results are consistent with the data on water at the interface (Figure 3).

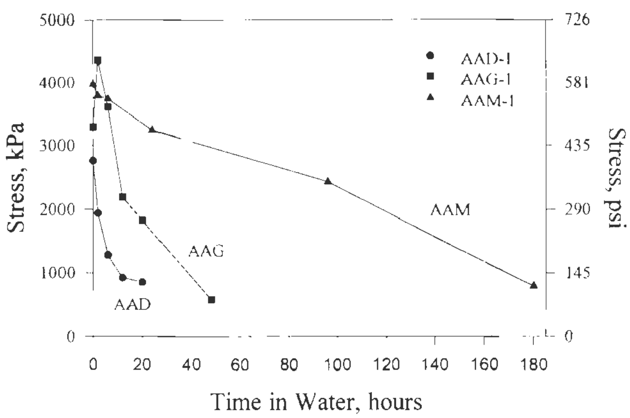


FIGURE 5 Adhesion of three SHRP asphalts on a granite substrate as a function of exposure time to distilled water.

In summary, the use of a pneumatic pull-off adhesion tester combined with a porous stub was found suitable for measuring the bonding strength of an asphalt on an aggregate in the dry condition as well as in the presence of water. This test provides useful data on the relative stripping resistance of different asphalts on a substrate. It is quantitative, quick, simple, reproducible, insensitive to operator, and portable. Therefore, it can be used in the laboratory and in the field. The pneumatic adhesion tester is commercially available and relatively inexpensive (<$2000), and the porous stubs can be made easily. As for the FTIR-MIR method, although further analysis on various organic films/substrate systems are needed, limited data on asphalts and polymers on SiO_2-covered Si substrates suggested that FTIR-MIR is useful for discriminating the stripping resistivity of different asphalts on a siliceous substrate at the molecular level. The use of this method for evaluating the effectiveness of five antistripping agents is being studied.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The laboratory tests using SHRP standard samples have shown the potential for applying the technique for screening asphalts and assessing water-stripping resistance. The laboratory tools used for the project are available at the National Institute of Standards and Technology for correlating the data with field results. Additional tests for field and laboratory correlation of data would be required for applying the FTIR-MIR method to field asphalt practice.

DEVELOPMENT OF GUIDELINES FOR LOW-COST SPRAYED ZINC GALVANIC ANODE FOR CONTROL OF CORROSION OF REINFORCING STEEL IN MARINE BRIDGE SUBSTRUCTURES

NCHRP-IDEA Project 3[1]

Alberto A. Sagues,[2] *University of South Florida, Tampa*
Rodney G. Powers, Florida Department of Transportation, Gainesville

IDEA PRODUCT

A low-cost corrosion control method for marine bridge substructures has been developed and tested for extending the life of marine bridge substructure components that are deteriorating because of the corrosion of reinforcing steel. A guidelines manual has been prepared for application of the technique to coastline bridge substructures exposed to saltwater spray and evaporation.

CONCEPT AND INNOVATION

The method consists of the innovative use of sprayed zinc anodes for cathodic protection. The application of the anodes is simple and involves low installation and maintenance costs when compared with conventional impressed-current systems. The deteriorated components are blasted clean and arc-sprayed zinc is deposited directly over the clean, exposed rebar and surrounding external concrete surface (see Figures 1 and 2). Application over patched concrete is also possible by forming an electric connection using a connecting stud.

The technique can be used for repair and corrosion control for a vast number of substructure members (piling, columns, footers, and struts) that are currently deteriorating in highway bridges along the U.S. coastline. The concept is successful in humid, warm-weather environments that are subject to corrosion of the reinforcing steel at points where the surface is exposed to saltwater spray or splash with intermittent evaporation.

IDEA PROJECT INVESTIGATION AND PROGRESS

A conceptual project was completed by the Strategic Highway Research Program (SHRP) for investigating the use of sacrificial sprayed zinc anodes for galvanic protection of reinforcing steel in marine bridge

FIGURE 1 Application of zinc anode.

[1]This IDEA project is a continuation of a SHRP-IDEA project and has been completed.
[2]Professor, Department of Civil Engineering and Mechanics.

FIGURE 2 Sprayed zinc concrete surface.

substructures. This IDEA project is a continuation of that SHRP project.

Seven test areas were selected for detailed examination in the substructure of the Howard-Frankland Bridge across Tampa Bay in Florida. As part of major rehabilitation, the bridge contains more than 11,000 m^2 of arc-sprayed zinc surface. The selected substructures include two prestressed beams, four pile caps, and a portion of a span underdeck.

The method consists of removing delaminated concrete from substructure elements where severe reinforcement corrosion had taken place and arc-spraying with zinc the exposed steel and surrounding external concrete surface after blast-cleaning. Galvanic interaction between the reinforcing steel and the surrounding zinc takes place as a result of metallic contact at the exposed steel and the presence of an adequate electrolyte (concrete in a high-humidity environment).

The sacrificial anode installations at the Howard-Frankland bridge were conducted with minimal difficulty by using commonly available commercial equipment. The physical integrity of the anodes was preserved throughout the entire 18-month test period. These installations, in addition to the other projects in the Florida Keys and elsewhere in Florida, demonstrated that the anode placement technology is well established.

The techniques for anode performance characterization were suitable for routine use and provided reasonably consistent results. As a result, these techniques were incorporated in an implementation guidelines document for general user application.

The present investigation has provided additional experience in the placement, operation, and performance monitoring of a relatively inexpensive cathodic protection system for marine substructure service. The results are consistent with expectations and prior testing and indicate that a significant amount of corrosion protection is being achieved. The information available to date is not sufficient to determine whether the sacrificial anodes will be a long-term alternative to impressed-current systems. However, the use of the sprayed anodes is an attractive alternative to conventional repairs that would use gunite or similar patching methods.

Conventional patching in a marine substructure involves a preparation and surface pretreatment similar to that used for the galvanic anodes. Application of the gunite finish requires portable spray equipment, skilled operators, and finishing procedures that, in the experience of the Florida Department of Transportation (DOT), result in costs on the order of several thousand dollars per patch for locations that require boat access. Also in the experience of Florida DOT and other transportation agencies, conventional patches in marine locations tend to develop new corrosion spalls about 2 years after application of the patch. The new spalls often develop at rebar surrounding the initial patch zone, possibly because the newly patched, chloride-free area is the site of predominantly cathodic reactions. This situation promotes the formation of a corrosion macrocell that aggravates the corrosion in the immediately surrounding anodic steel, which is still in contact with concrete with a high chloride ion concentration. Sacrificial sprayed anodes cost about the same as conventional patching, or even less if no cover over the exposed spall is needed for structural or aesthetical reasons. However, the findings of this and previous investigations indicate that, unlike the conventional patch, the sacrificial anode provides positive protection by reducing the corrosion rate of the steel. The protection extends also to the region surrounding the original spall, mitigating the possible effect of corrosion macrocells.

Experience with installations at the Florida Keys shows that sacrificial anodes have survived up to 5 years of field service, with mostly positive results. For example, a very recent inspection of 40 zinc-sprayed footers at the Seven Mile bridge in the Florida Keys showed that at the end of a 3-year test period, only 12 had experienced new spalls. Because those installations are on structures that had corroding epoxy-coated rebar, it is possible that at least some of the new spalls resulted from lack of connection (and consequent absence of protection) to electrical discontinuous elements of the rebar cage itself. Experimental conventional patch repairs at the same bridge showed new spalls typically within 2 years. While both the South Florida installations and the Howard-Frankland test site will be subject to continued monitoring during the following years, the evidence to date supports the use of the technique as an alternative to conventional repairs when limited-term corrosion protection measures are being contemplated.

Long-term protection strategies involving sacrificial anodes depend on the actual field service life of the anodes, which is not yet fully documented. The field record shows that useful service has been documented for up to 5 years. An upper limit of about 10 to 15 years has been estimated from anode consumption based on the amount of zinc available, typical current density demands, and expected levels of autocorrosion. The choice of galvanic versus impressed-current anodes or other strategies for specific substructure members will be dictated by economic factors such as the required remaining service life of the entire structure, cost of replacing the galvanic anodes periodically versus a one-time impressed current installation cost, replacement cost of the substructure member itself, and eventual obsolescence of the structure.

This protection method is applicable to marine substructure elements of bridges and other structures in warm-weather environments, subject to corrosion of reinforcing steel at points where the surface of the concrete is exposed to saltwater spray or splash with intermittent evaporation. The procedure is intended for substructures that have already shown signs of corrosion-induced deterioration, including severe spalling of the concrete cover. The procedure has been successfully tested with plain and epoxy-coated reinforcing steel structures that had experienced severe corrosion. The method has also been tested in piling where prestressed strands were present.

The method has not been tested in structures in cold climates, structures with corrosion related to concrete carbonation, and structural members where prestressed steel serves as a critical structural component. Laboratory testing indicates that performance is not likely to be adequate when the anode surface is not subject to seawater spray. At the other extreme, field experience indicates that anode application is difficult and anode life is very limited when complete immersion of the anode in salt water takes place (as in the tidal zone or at seawater pools on the horizontal surface of footers).

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The *Guidelines for Implementations* document prepared under this project will be available as a TRB-IDEA report to users interested in employing this corrosion protection method. The guidelines contain the following chapters:

1. Types of Structures Suitable for Implementation,
2. Field Assessment of the Structures To Be Protected,
3. Sprayed Zinc Anode Configuration and Area To Be Metalized,
4. Electric Contacts,
5. Surface Preparation,
6. Zinc Application Equipment,
7. Application Procedure,
8. Performance Monitoring and Maintenance,
9. Service Life Estimate, and
10. Example of Typical Contract Specifications.

The guidelines are being used by the Florida DOT and were based on results from previous successful installations at the Howard-Frankland Bridge for the FHWA Experimental Features Project 92-01.

EXPLORING THE FEASIBILITY OF REPLACING LATEX WITH ASPHALT EMULSION FOR USE IN BRIDGE DECK OVERLAYS

NCHRP-IDEA Project 4[1]

Jan Olek,[2] *Menashi D. Cohen,*[3] *and Sidney Diamond*[3]
Purdue University, West Lafayette, Indiana

IDEA PRODUCT

A new construction material consisting of a mixture of traditional components of plain portland cement concrete (cement, water, and aggregate) and asphalt emulsion was explored. The asphalt emulsion forms a membrane-like film throughout the microstructure of concrete. This film reduces the permeability of the concrete by filling up the capillary pores and reducing their interconnectivity. The concrete modified with asphalt emulsion appears to have excellent freezing and thawing resistance, reduced chloride ion permeability, and improved durability; it offers the potential for increasing concrete performance of highway structures.

CONCEPT AND INNOVATION

The unique feature of this innovation is the use of asphalt emulsion for the purpose of modifying the properties of portland cement concrete. In this application, the asphalt emulsion is treated as a polymeric material that essentially impregnates the microstructure of portland cement concrete. The resulting product combines the advantages of portland cement concrete (strength and stiffness) and polymer (ability to partly plug pores and form a membrane-like film, which reduces the ingress of aggressive or corrosive elements). Considerable advances in asphalt emulsion technology have been introduced in recent years, especially the more widespread use of non-ionic emulsifiers and the addition of elastomers, which have greatly increased the potential for successful application of such materials in portland cement concrete modification.

The proposed IDEA product can offer substantial benefits in the area of durability of concrete structures, especially those exposed to severe environmental conditions, including concrete bridge decks and highway pavements.

IDEA PROJECT INVESTIGATION AND PROGRESS

Plain, unmodified portland cement concrete is a porous material (see Figure 1). Under the service conditions, the pores existing in the microstructure are penetrated by water or other solution, a process that frequently results in various durability problems, including the corrosion of steel, freeze-thaw deterioration, and deterioration due to sulfate or other chemical attacks.

The primary objective of this study was to develop and investigate an asphalt emulsion–modified concrete system (see Figure 1) with improved mechanical and durability properties for highway and bridge deck applications. A preliminary study was conducted on selected asphalt emulsions to determine their compatibility with portland cement systems. These investigations were performed on portland cement mortars that were prepared by selecting constant proportions of portland cement and fine aggregate and varying the amount of asphalt emulsion from 5% to 40% in 5% increments. These preliminary studies involved determining the workability of a fresh mortar by means of flow table measurement as well as assessing the compressive strength after 3 and 7 days of moist curing.

Based on the results of the preliminary studies, a slow-setting anionic asphalt emulsion with a harder base asphalt cement was selected for use in further experiments with concrete. This emulsion was given the symbol SS-1h. Since it was found that at every level of

---

[1]The IDEA project started in April 1993 and has been completed (December 1994).
[2]Assistant Professor, Department of Civil Engineering.
[3]Professor, Department of Civil Engineering.

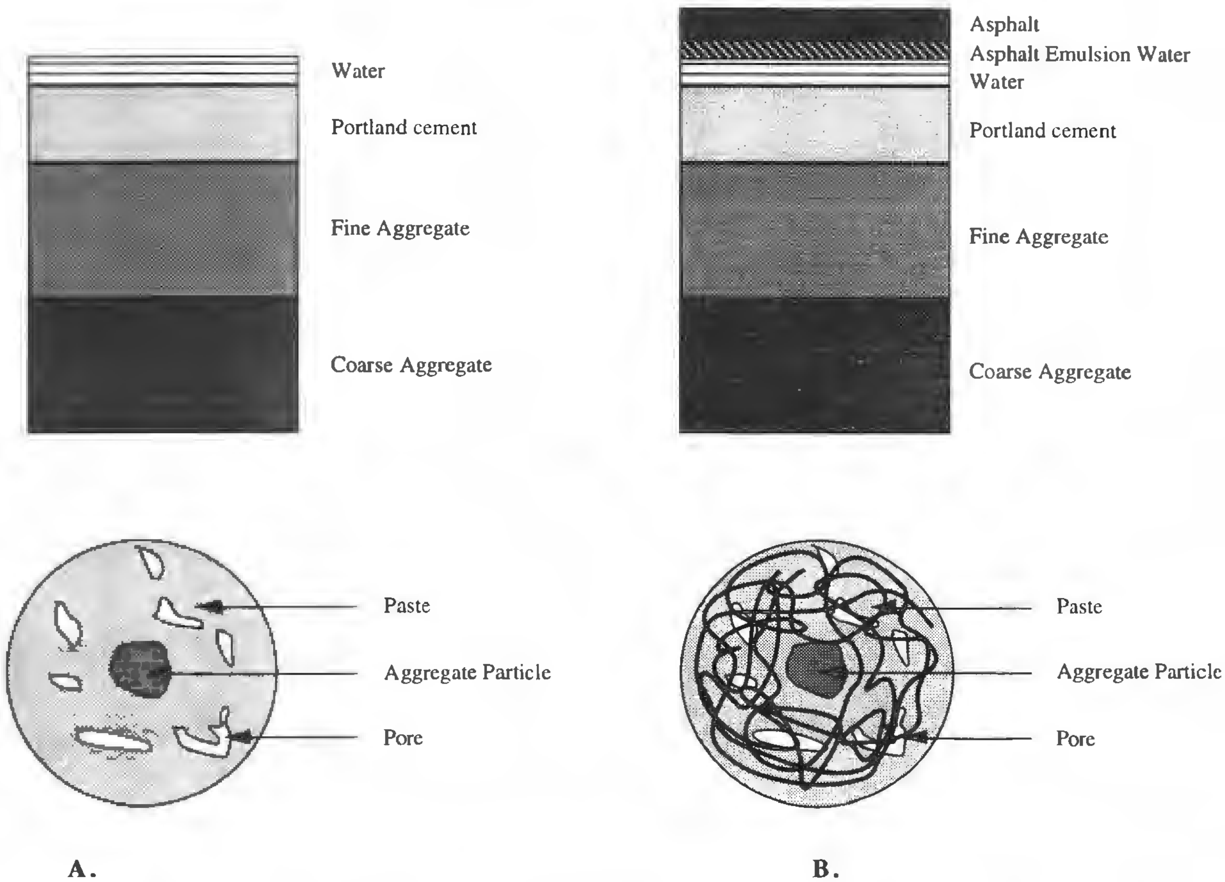


FIGURE 1 Schematic view of microstructure and composite of (a) plain and (b) asphalt emulsion–modified portland cement concrete.

asphalt emulsion addition, both the flow and the compressive strength of mortars were reduced, it was decided that each concrete batch containing asphalt emulsion would also contain superplasticizer. The addition of superplasticizer allowed for production of workable concrete with a lower water-cement ratio and higher strength.

Following the preliminary studies, the main research efforts were concentrated on the following tasks:

- Design of concrete mixtures containing 10 and 20 percent (by the weight of cement) addition of the selected asphalt emulsion; and
- Evaluation of mechanical and permeability properties. Tests were performed to determine the workability, strength, and dynamic modulus of elasticity of the asphalt emulsion–modified concrete. In addition, some durability-related parameters, such as chloride permeability and freeze-thaw resistance, were also investigated. Finally, porosity of the hardened asphalt emulsion–modified concrete was also examined.

Five different concrete mixes were prepared for this study:

1. Conventional portland cement concrete (CPCC) as the reference;
2. Asphalt emulsion–modified concrete with 10% of SS-1h asphalt emulsion and a naphthalene sulfonate superplasticizer (PC10SSC);
3. Asphalt emulsion–modified concrete with 20% of SS-1h asphalt emulsion and a naphthalene sulfonate superplasticizer (PC20SSC);
4. Asphalt emulsion–modified concrete with 10% of SS-1h asphalt emulsion and a naphthalene sulfonate superplasticizer and an air detraining agent (PC10SSDC); and

5. Asphalt emulsion–modified concrete with 20% of SS-1h asphalt emulsion and a naphthalene sulfonate superplasticizer and an air detraining agent (PC20SSDC).

A summary of all experiments performed in this part of the study is presented in Figure 2. The first row of boxes in this figure contains a symbolic representation of the fact that concrete mixes were designed by altering the composition of mortars from the preliminary studies by adding coarse aggregate and superplasticizer.

The percentage of asphalt emulsion added to the asphalt emulsion–modified concretes was based on the weight of the cement. The water-cement ratio for the reference concrete was 0.48. The water-cement ratio for all asphalt emulsion–modified concretes was reduced to 0.40, so higher compressive strength could be obtained. The amount of portland cement added to all concrete mixes was kept constant. However, the amount of water added to the concrete mixes was adjusted according to the percentage of asphalt emulsion used in a concrete as well as the moisture content of fine and coarse aggregates. Since the SS-1h asphalt emulsion used for this study contained 40% water, an equivalent amount of water was subtracted from the mix water. The actual amount of water added to the concrete mix was also affected by the moisture content of fine and coarse aggregates. When the moisture content of fine and coarse aggregates was below their absorption capacities, extra water was added to the

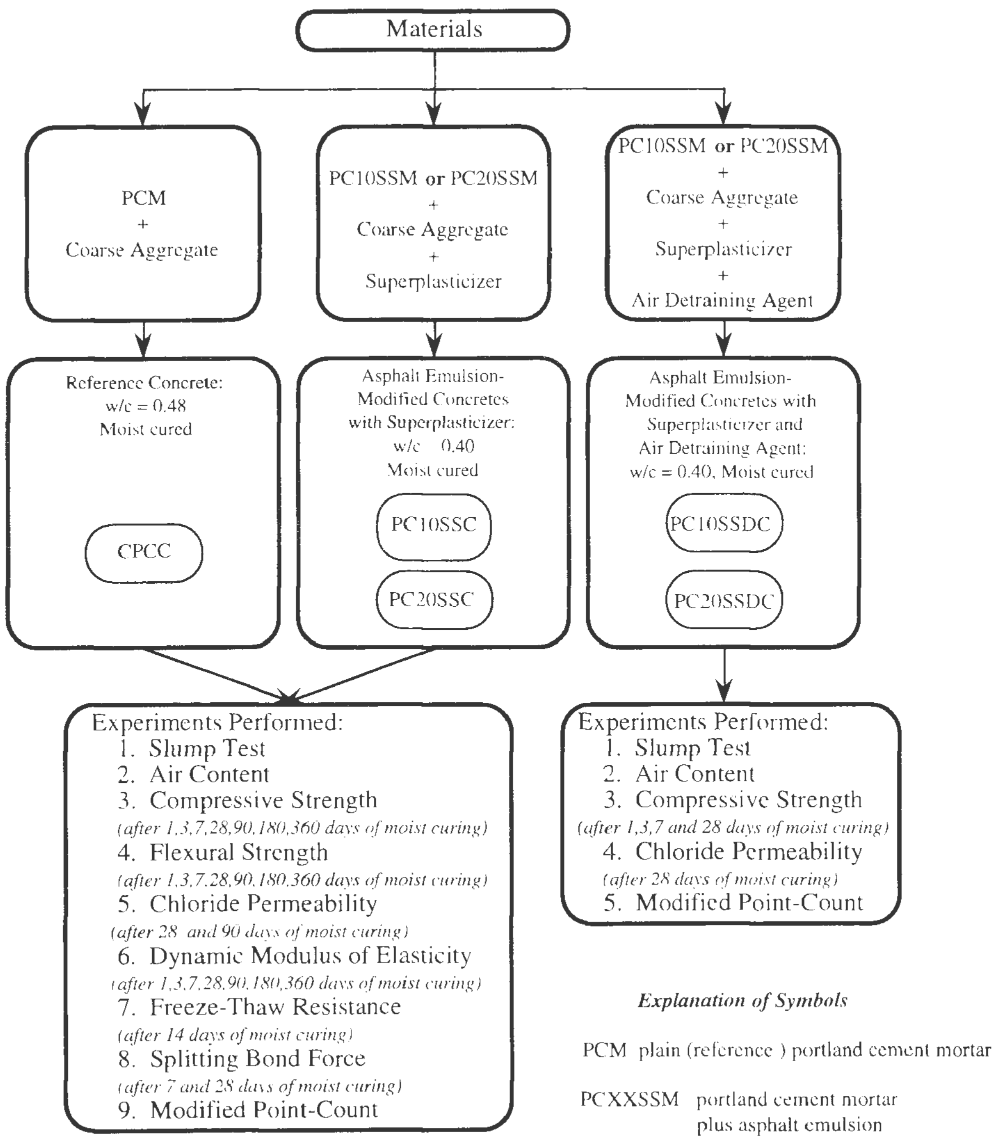


FIGURE 2 Flow chart of concrete study portion of research program.

concrete mix to bring aggregates to the correct moisture level. In cases where the moisture content of the aggregates was higher than their absorption capacity, the appropriate amount of water was subtracted.

After casting, all specimens were covered with plastic sheets and cured in laboratory air for 24 hours. They were then demolded. Finally, all specimens were transferred to a 100% relative humidity fog room and stored there until testing time.

The selected test results from the first series of concrete experiments are shown in Figures 3–5. In general, untreated (without air detraining agent) asphalt emulsion–modified concretes developed considerably lower strength than conventional portland cement concrete. This is most likely due to the high content of entrained air resulting from the use of asphalt emulsion. After the excessive air content was reduced, the strength performance of asphalt emulsion–modified concretes improved (see Figure 3).

The chloride permeability of asphalt emulsion–modified concretes was slightly better than that of conventional portland cement concrete (see Figure 4), and their freezing and thawing resistance was excellent (Figure 5), although these results surely reflect the high air content of the samples.

In summary, the performance of asphalt emulsion-modified concrete demonstrated during the first stage of this project, although adequate, was at best comparable to or only marginally better than that of a plain, unmodified concrete. A critical analysis of these findings led to the conclusion that further modifications of both mix proportions and production techniques were needed if significant performance improvement was to be achieved.

It was therefore decided to start the second phase of the investigation to explore the influence of different curing regimes and the addition of mineral admixtures on the properties of asphalt emulsion–modified concrete.

In the new series of tests the samples were moist-cured only for a short initial period of 24 or 48 hours. This brief period of moist curing was followed by a period of air curing. This modified curing procedure accelerated the evaporation of water from concrete (including the water from asphalt emulsion) and sped up the development of asphalt "film" throughout the microstructure of the concrete.

For comparative purposes, a second series of companion samples following the same curing regime as used in the first stage of the project (that is, moist curing in the fog room) was also tested. The second series' test results for moist-cured samples are very similar to those obtained during the first series. This indicates that asphalt emulsion–modified concrete can be produced in a reproducible fashion, using the standard mixing and batching equipment. A limited number of tests have also been performed on samples containing the addition of both asphalt emulsion and either silica fume or class C fly ash at 10% by weight of cement replacement level.

The results obtained for air-cured samples with and without the mineral admixtures are presented in Figures 6 and 7. Four mixes were prepared for this study: (a) CPCC as the first reference, (b) asphalt emulsion–modified concrete with 10% of SS-1h asphalt emulsion, naphthalene sulfonate superplasticizer, and an air detraining agent (AEMC); (c) conventional (10% of silica fume by weight of cement) silica fume concrete with a naphthalene sulfonate superplasticizer (CPCSFC)

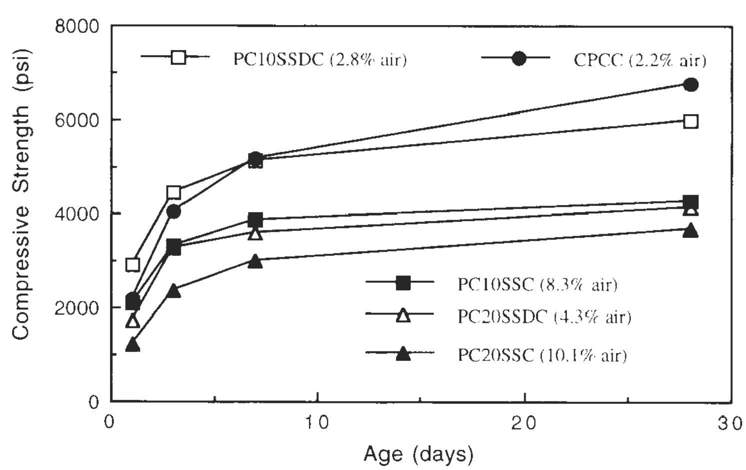


FIGURE 3 Compressive strength-curing time relationship for plain and asphalt emulsion–modified concrete with and without detraining agent.

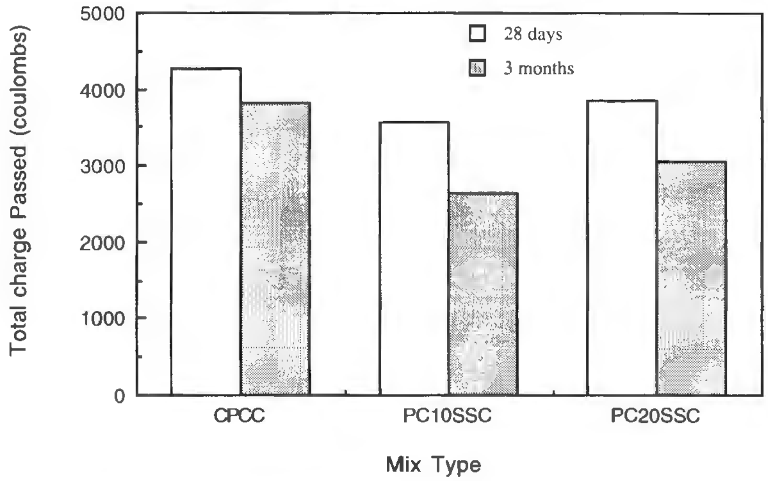


FIGURE 4 Rapid chloride permeability results for moist-cured plain and asphalt emulsion–modified concrete.

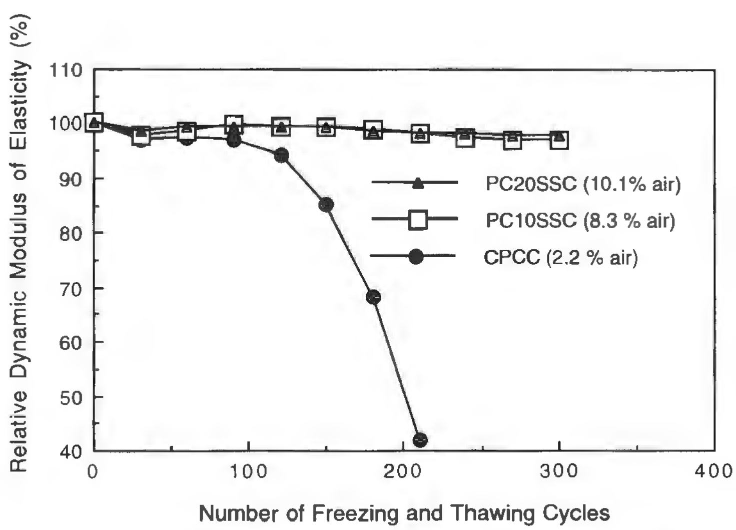


FIGURE 5 Freezing and thawing test results for plain and asphalt emulsion–modified concrete.

as the second reference; and (d) asphalt emulsion–modified concrete with 10% of SS-1h asphalt emulsion, naphthalene sulfonate superplasticizer, and an air detraining agent (AEMSFC).

The results from rapid chloride permeability tests obtained for air-cured samples are superior to those obtained for wet-cured samples. This indicates that exposure of samples modified with asphalt emulsion to the environment, which promotes the loss of water by evaporation, is very beneficial to the properties of the final product. Even at the relatively early age of 28 days, the asphalt emulsion–modified samples reached the "low"

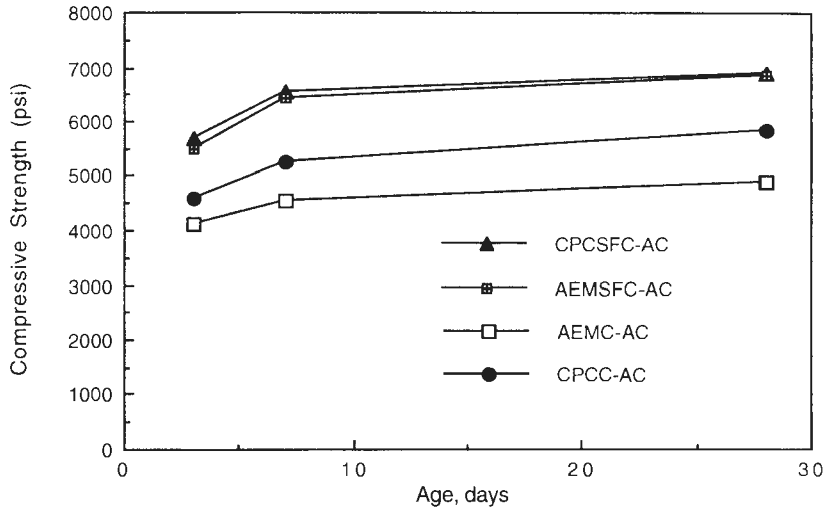


FIGURE 6 Compressive strength development of air-cured samples.

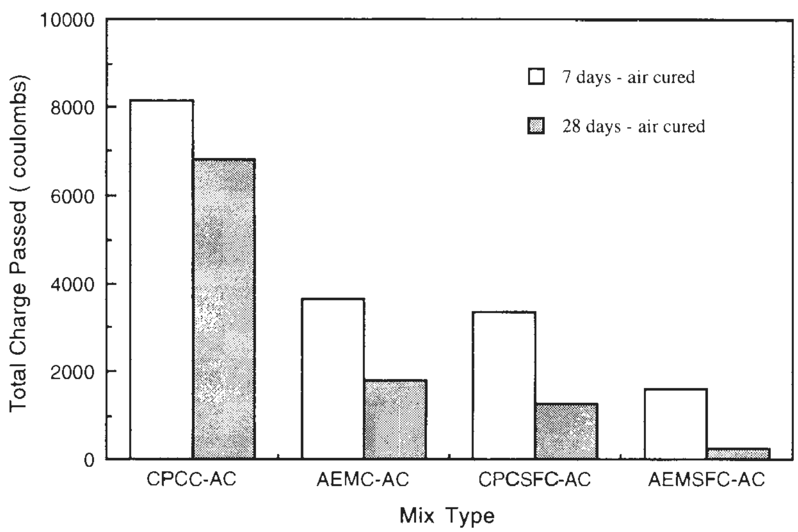


FIGURE 7 Rapid chloride permeability results of air-cured samples

chloride permeability category (1,000 to 2,000 coulombs, according to AASHTO T277) and practically matched the performance of the reference silica fume concrete. The most significant reduction of total charge passed in rapid chloride permeability tests was observed in samples containing both silica fume and asphalt emulsion addition: after 56 days of air curing, these samples were completely impenetrable (0 coulombs of charge).

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

Further research for field application of the proposed technology will be discussed with the Indiana Department of Transportation. The results will be published in technical literature and presented at technical conferences.

MAGNETIC RESONANCE FOR IN SITU DETERMINATION OF ASPHALT AGING AND MOISTURE CONTENT

NCHRP-IDEA Project 5[1]

J. Derwin King and Qing Wen Ni
Southwest Research Institute, San Antonio, Texas

IDEA PRODUCT

The concept of a mobile system based on magnetic resonance (MR) technologies was successfully tested; The system is suitable for in-motion inspection of asphalt pavements and provides a potential means for rapid determination of pavement aging, moisture content, and perhaps other parameters that are important in assessing the condition of asphalt concrete roadways. It is expected that an experimental model of this inspection system will be assembled and evaluated in a future project.

Inspection of highway structures and roadway pavements relies heavily on visual examinations (*1*) supplemented with limited non-destructive evaluation (NDE) techniques, photography, and surface profile measurements. NDE techniques that examine not only the surface but also the interior of the pavement for distress would be advantageous in assessing roadway condition and planning repair or rehabilitation. Many of the properties of asphalt are understood quantitatively and have been reasonably well analyzed and controlled for many years (*2,3*). These important properties include elastic behavior, strength, elementary creep, and shrinkage characteristics (*3*).

However, standardized destructive and non-destructive test methods used to measure asphalt properties for quality control and prediction of remaining service life (*3–6*) often lack sufficient accuracy and reliability and are not applicable to in situ assessment of existing asphalt concrete pavements. From previous studies it is known that as asphalt deteriorates the elastic-like binders become more rigid and less flexible (*3*). Innovative MR technologies have been shown to be capable of making rapid and reliable in situ measurements of such properties within materials for other applications. The feasibility of this means for accurate assessment of asphalt pavement materials has been investigated in this project.

CONCEPT AND INNOVATION

To obtain MR data, the material to be inspected must be located in a magnetic field H_o and, for transient MR, must be exposed to bursts (or pulses) of a radio frequency (RF) field, H_1. For nuclear magnetic resonance (NMR), selected atomic nuclei in the sample will strongly absorb (and subsequently re-emit) energy when the frequency of the RF field, f_o, is related to the magnetic field intensity by $f_o = \gamma H_o/2\pi$ where γ is the gyromagnetic ratio of the particular absorbing nuclear isotopes. For hydrogen, the only element in asphalt that can be detected with adequate sensitivity for practical application of NMR to highway measurements is f_o = 42.6 MHz/tesla. The hydrogen transient NMR (HTNMR) signal is of an amplitude proportional to the total hydrogen in the measured volume of the material.

When nuclei absorb energy from the applied RF field, the thermal equilibrium is changed and the absorbed energy is exchanged exponentially with the surroundings. This results in an emitted transient signal of (nominal) frequency f_o, which is characterized by two primary time constants: the spin-lattice (T_1) and the spin-spin (T_2) relaxation times. T_1 is related to the time required for nuclei in the material being measured to become completely polarized in a magnetic field. T_2 determines how rapidly the transient NMR signal decays in a perfect magnetic field. These two relaxation times are related to the viscosity and hence, in the case of asphalt paving, to the aging and moisture content. In complex materials,

[1]The IDEA project started in April 1993 and has been completed (December 1994).

both T_1 and T_2 may have multiple components with each component representative of different molecular constituents, binding states, or the hardness or viscosity of the constituents in the material. The amplitude and time constant of all these NMR signal components are used as analytical tools for assessing physical and chemical characteristics of materials; work during the IDEA project has shown such data to be indicative of asphalt aging and moisture content.

Electron paramagnetic resonance (EPR) is similar in principle to NMR but responds to the unpaired electrons instead of nuclei. Such electrons occur in many pyrolyzed and natural hydrocarbons, such as coal, crude oil, and asphalts, due to free radicals or broken bonds and may also occur in many organometallic compounds such those involving vanadium, nickel, manganese, or other paramagnetics. EPR occurs at a nominal frequency of 2.8 MHz/oersted. Compared with NMR the frequency and sensitivity of EPR in the same field are much greater and the time constants T_1 and T_2 are generally much shorter. These factors are desirable for rapid, high-sensitivity in-motion applications and make EPR attractive for in situ highway measurements. Implementation of the EPR technology for in situ measurements of asphalt pavements can supplement and add to the specificity of data available from NMR. Both EPR and HTNMR are basically amenable to implementation in inspection apparatus for non-contacting, in situ measurements from a moving vehicle. Such apparatus has been previously developed for measuring moisture in concrete bridge decks and in large acreages of agricultural soil, detecting buried explosives, and measuring the thickness of coal overlying the rock substrates in coal mining. Compared with other sensing methods, MR offers significant advantages for in situ asphalt inspection. It is

- Non-destructive, non-contacting, and non-intrusive;
- Safe: no ionizing radiation is used or produced;
- For bulk measurements, instead of surface conditions only;
- Analytical: constituents and molecular binding state; and
- Rapid and suitable for on-line, in-motion measurements.

IDEA PROJECT INVESTIGATION AND PROGRESS

Samples of 12 asphalt materials given in Table 1 were selected from the Materials Reference Library in Austin, Texas, to be representative of wide variations in properties that are believed to be relevant to asphalt aging and that are either pertinent to measurement by MR or can possibly affect MR measurements. Small samples of each of these 12 neat asphalts were prepared in 25-mm (nominal) glass vials for the NMR tests at depths ranging from 4 to 6 mm. The vials were capped and remained sealed throughout the measurement process except when controlled tests to remove volatiles or effect oxidation were under way. The samples for EPR measurement were prepared in a similar fashion in 4-mm-diameter sample tubes with weights ranging from 34 to 72 mg.

The asphalt samples were measured, as initially prepared, to determine the HTNMR signal amplitude, complex T_1 and T_2 properties, and EPR spectral properties. Then, to simulate the initial stages of curing and aging, the NMR samples were placed in a vacuum oven at 60°C for 20 hours to remove the volatiles. This approach allows the volatiles to be removed independently of oxidation. After the vacuum oven treatment, the weight loss was comparable to that reported for the thin-film oven test (Table 1). The "volatized" samples were again measured to determine the HTNMR properties. Then, to simulate effects of long-term aging due to oxidation, the samples were exposed to an oxygen atmosphere of 300 psig at a 60°C for 740 hours. The samples were removed, cooled, and weighed to determine the amount of oxygen that had been absorbed at several intervals and to again measure the HTNMR properties. The total weight increase during oxidation varied somewhat from sample to sample but was on the order of 2%.

HTNMR data were acquired at room temperature (23°C nominal) and at 60°C in the laboratory NMR system at a frequency of 27 MHz. The measurements included the peak free induction decay (FID) signal; solid echo; Hahn echo; CPMG; FID ratio; spin-lattice relaxation time (T_1), two components, (T_{21} and T_{22}) of the spin-spin relaxation time (T_2) and the spin-lattice relaxation time in the rotating frame ($T_{1\_}$).

The EPR samples were examined only at room temperature using a Varian EM-500 EPR spectrometer. This system operates at a nominal frequency of 10 GHz and acquires data by sweeping the magnetic field over a selected range that includes the EPR. These data have been correlated with the NMR data to identify ferromagnetic and paramagnetic effects from iron, vanadium, and manganese in the asphalts.

The peak amplitude of the HTNMR signal, in volts per gram of sample, provides a direct measure of the total hydrogen content of the asphalts and ranges from 0.622 for ABM-1 to 0.802 for AAA-2. For a given type of asphalt concrete, this parameter can be used to provide an accurate measure of the amount of asphalt per unit volume. The T_1 parameter was found to decrease with

TABLE 1 Properties of Asphalt Samples Used in Magnetic Resonance Study

Asphalt Code AC Grade	Crude Source	Viscosity 60°C. Poises	Penetration 25°C. 0.1 mm	Trace Elements		Molecular Weight (Toluene)	Asphaltenes (n-Heptane)	TFOT Aging	
				V/Ni ppm	Fe (ppm)/ S (%)			% Mass Change	Viscosity Ratio (60°C)
AAA-2 200/300 PEN	Lloydminster	363	291	138/27	--/6.0	790	16.2	-.537	2.39
AAB-2 AC-5	Wyoming Sour (Dist)	403	166	163/36	--/5.4	840(?)	16.7	-.015	2.66
AAC-1 AC-8	Redwater/Gulf Boundary Lake	419	133	146/63	--/1.9	870	10.1	-.259	2.42
AAD-2 AR2000	California Coastal (Dist)	600	195	266/135	--/8.3	700	21.3	-.709	2.86
AAE 60/70 PEN	Lloydminster (Air Blown)	3634	73	179/91	6/5.2	820	22.9	-.289	3.19
AAF-2 AC-10	West Texas Sour	867	82	102/22	--/4.6	840(?)	13.0	-.069	2.32
AAK-1 AC-30	Boscan (Dist)	3256	70	1480/142	24/6.4	860	20.1	-.548	2.98
AAM-1 AC-20	West Texas Intermediate (SDA)	1992	64	58/36	255/1.2	1300	4.0	-.052	1.98
AAS-2 AC-10	Arabian Heavy	1220	96	133/37	--/6.8	960(?)	17.1	-.016	3.25
ABC AC-20	Mississippi Valley	2091	76	37/25	12/6.4	870	25.6	-.219	2.40
ABL-2 EB-10	Boscan (Emulsion Based)	1097	169	1484/134	--/6.3	--	17.0	-1.335	3.37
ABM-1 AR-4000	California Valley Lime-treated crude	2230	48	63/111	--/1.3	--	7.1	-.248	1.62

temperature for all the asphalts and ranges from 75 to 146 milliseconds at 23°C and 50 to 114 milliseconds at 60°C. This parameter is important in analyses of materials and also provides a measure of the time that a material must be exposed to a magnetic field before an appreciable NMR signal may be obtained. For measurements from a moving vehicle, T_1 sets the maximum speed for a given length of magnet. For a magnetic field 1 meter long, the maximum vehicular speed for NMR measurement of asphalt pavements is on the order of 2.28 m/s (5.1 mph) for an accuracy of 5%.

The initial part of the HTNMR signal was found to decay rapidly with a time constant T_{21} and then more slowly at a rate T_{22}. The T_{21} component is associated with the more solid part of a complex material , whereas T_{22} is associated with the softer or more fluid, lower-viscosity constituents. The T_{21} values from the harder, more solid component of the 12 asphalt samples varies, from 14.8 microseconds (μsec) for AAK-1 to 18.0 for AAB-2 at 23°C. At 60°C all T_{21} values are increased and range from 22.5 μsec for AAK-1 to 27.6 for AAA-2. This indicates a softening of the more solid component. The observed value of T_{22} at 23°C ranges from 73 μsec for ABM-1 to 164 μsec for AAA-2. At 60°C the softening of the asphalt increases the observed value of T_{22} from 237 μsec for AAK-1 to 476 μsec for AAB-2.

The HTNMR data for the neat, as-received samples were correlated with several asphalt properties as provided by the Materials Reference Laboratory. The T_{21} component shows quite good correlation with penetration at 23°C, and at 60°C the data correlate with the viscosity. The T_1 times of all asphalts except AAK-1 and ABL-2 correlated quite well with penetration and viscosity. The high vanadium content in AAK-1 and ABL-2 reduced T_1 through paramagnetic effects.

T_{21} was consistently reduced by loss of the volatiles as would be expected from the hardening of the more solid component of the asphalts. The effect on T_{22} was not as consistent, with some samples showing an increase and others, a small decrease at both temperatures.

For the first 100 hours of oxidation, the presence of increasing amounts of paramagnetic oxygen in the asphalts caused a consistent reduction in T_1. Additional oxidation caused the trend to reverse, due apparently to hardening of the asphalt and a resultant increase in T_1. However, the $T_{1\rho}$ data, Figure 1, show a consistent increase with oxidation for all aging asphalts.

Two changes were observed in the T_2 of the asphalts as oxidation increased: a hardening of the short T_{21} constituent and a softening of the long T_{22} constituent. The T_{21} data showed a small but consistent decrease with oxidation, which indicates a hardening of the more solid component of the asphalt. The increase in the hardness or rigidity of this constituent was more evident in the T_{21} data at 60°C than at room temperature. The HTNMR data also showed an appreciable increase in T_{22} as a function of oxidation aging time. This indicates a softening of the long T_{22} constituent in the asphalt that is also more apparent in the T_{22} data at 60°C.

Additional oxidation aging time is needed to evaluate the observed trends in T_1 and T_2 to the end point. However, the results show positive changes in NMR parameters that indicate aging and that can be readily measured with an appropriate MR instrumentation system usable in the field.

The EPR spectra showed a response from the broken bonds in the hydrocarbon portion of the asphalt plus that from significant amounts of paramagnetic metals. All of the asphalts showed the typical pyrolized material response and all the asphalts except AAM-1 and ABC showed a significant multipeak vanadium spectrum though an order of magnitude (or more) smaller than that from AAK-1 and ABL-2. These results are in agreement with the vanadium content given in Table 1. In addition to detection of vanadium and other paramagnetic and ferromagnetic constituents, the EPR data may provide direct information on asphalt aging. This possibility needs to be investigated further.

HTNMR and EPR measurements were made on two very dry samples of asphalt pavement removed from roadways many years old. Sample 1 exhibited weak bonding strength and some resilience. It could be broken by hand, but not easily. Sample 2 was older and very deteriorated; it crumbled easily and had little bonding strength. The HTNMR data obtained from these pavement samples in the laboratory NMR showed very weak signals with a very short decay time T_2 (about 15 μsec.). The weak signal is attributable to the small amounts of hydrocarbon (asphalt) remaining in the mixes compared with the amount of aggregate. The T_{22} component of the signal for the older sample was very weak. This indicates that little of the resilient asphalt remains in this mix as is apparent from the physical characteristics. Hahn echo data for Sample 1 showed the existence of a much larger T_{22} component in the NMR signal. An analysis of these data indicates T_2 signal components with time constants of 0.65 and 4.41 millisecond in addition to the very short (14.9 μsec) component determined from the NMR FID signal. This indicates magnetic inhomogeneity, which suggested the presence of ferromagnetic constituents in the aggregate-asphalt mix. This was confirmed by the EPR data.

EPR data from Sample 1 showed a very broad signal, which is attributable to a ferromagnetic constituent in the asphalt-aggregate mix. This constituent undoubtedly accounts for the short T_2 observed in the NMR FID data.

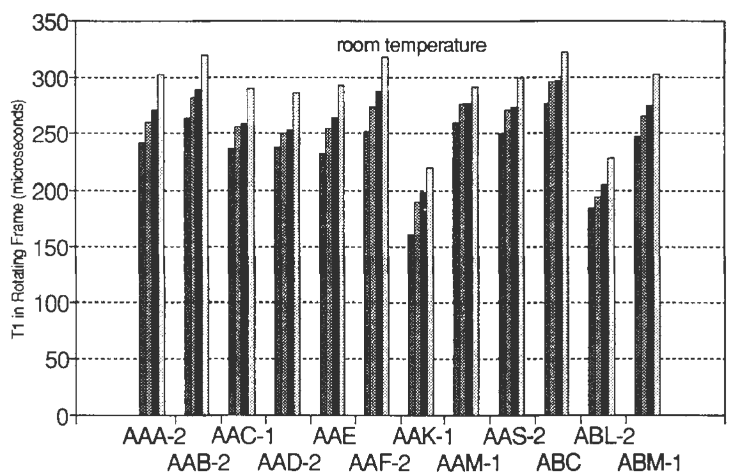


FIGURE 1 NMR T_1 relaxation time before and after oxidation at 300 psi for 60, 100, 400, 570, and 740 hours at 60°C for 12 asphalts.

Weaker fine structure in the spectra indicates an appreciable vanadium content in addition to the iron and normal hydrocarbon response. The EPR trace from Sample 2 showed a broad iron signal component that is much weaker than the multipeak spectra. The expanded EPR signal from Sample 2 was indicative of the normal hydrocarbon signal plus a multipeak spectrum (*6*) indicative of manganese. These results support the need for EPR data to supplement the HTNMR data and provide a basis for compensation of the NMR measurements for effects of ferromagnetic and paramagnetic constituents in asphalt-aggregate mixes.

The NMR system as previously developed for FHWA for measurement of moisture in concrete bridge decks was tested for in situ measurement of asphalt pavements but was found to be inadequate. This system has a surface access (one-sided) sensor to allow non-intrusive detection of hydrogen NMR signals from the interior of materials with the sensor above the surface. The magnet, sensor coil, transmitter power, and detector sensitivity are adequate to obtain moisture signals at 2.1 MHz from a band of material about 0.1 inch (2.5 mm) thick at selected depths ranging from 0.5 to 4.0 inches (12 to 100 mm) below the surface.

However, the system does not incorporate provisions for solid echo measurements, and the combination of transmitter pulse width and receiver recovery time prevents detection of the short transient NMR signal components from aged asphalt pavements. While the system is acceptable for the relatively slowly decaying signal from moisture in concrete, it could not detect the rapidly decaying ($T_{21} \approx 15$ μsec) signal that is the primary component of the asphalt pavement response.

To overcome this problem and to provide additional signal processing capability, the FHWA system was temporarily interfaced with a more versatile laboratory-type NMR system. This combination made possible the detection of HTNMR signals from sections of the aged asphalt pavements (Samples 1 and 2 previously described) in simulated in situ tests, i.e., from the surface of materials with the detection zone set to be 1 inch (25 mm) into the pavement samples. The signal-to-noise voltage ratio for the NMR echo response from the asphalt pavement was on the order of 4:1, or 12 dB. The composite in situ NMR system was also used for measurements of the asphalt pavement on a parking lot. This pavement is approximately 5 years old, in good condition, and apparently not showing deterioration due to aging. Very useful solid echoes were obtained in situ from within the asphalt pavement at a depth of 1 inch below the sensor surface.

In summary, the results of the study showed good correlation of the NMR data with the viscosity parameters and with aging induced by loss of volatiles and by accelerated oxidation. In situ NMR tests using the previously developed FHWA system produced weak but detectable signals from dry asphalt pavements. The weak signals result from the low concentration of asphalt in the pavement, from the limited sensing volume in the magnet used with this instrument, and from limitations in instrument capability to adequately sense the very short T_2 component of the asphalt-aggregate mix. These limitations are correctable in a system appropriately designed for asphalt inspection. EPR studies of the neat asphalts showed the typical hydrocarbon response from all samples plus a large multipeak vanadium spectrum from some samples, particularly AAK-1 and ABL-2. Vanadium spectra of lower amplitude were observed in most other samples in proportion to the concentration of this element in the different asphalts. The EPR vanadium signal can be used to provide a basis for correction of the NMR data for the effects of this paramagnetic element on the NMR data to make the pavement inspection independent of the type of asphalts and aggregates. An inspection system based on a combination of EPR and NMR, using the same magnet and other apparatus common to the two methods, is believed to offer the potential for in situ pavement inspection that is substantially immune to the variations in the different asphalts and aggregates. All the pertinent NMR and EPR data needed to determine the effects of asphalt aging are amenable to in situ measurement from a moving vehicle.

The recommended system design configuration in Figure 2 incorporates both HTNMR and EPR subsystems in an integrated, trailer-mounted configuration using a common magnet. The automated data acquisition and data processing uses the NMR data as the primary pavement condition sensor and the EPR data to correct for the effects of ferromagnetic and paramagnetic constituents in the asphalt. These data are used to provide an indication and recording of asphalt aging and moisture under static or in-motion conditions. In addition, the system acquires and stores complete NMR and EPR data for additional processing to assess other pavement data that may be of interest. An integral engine-generator provides electrical power for the system. The design is expected to permit in-motion data acquisition and processing at vehicular speeds up to 10 kmh (6 mph). The system measures the MR properties of asphalt pavement in a band about 0.1 inches thick and 4 inches wide located from 0.5 to 1.0 inches, as selected, below the top surface. The data are time-averaged for selected periods, ranging from 10 to 100 seconds, before readout. In a future project, it is expected that this system will be fabricated in experimental form and used to

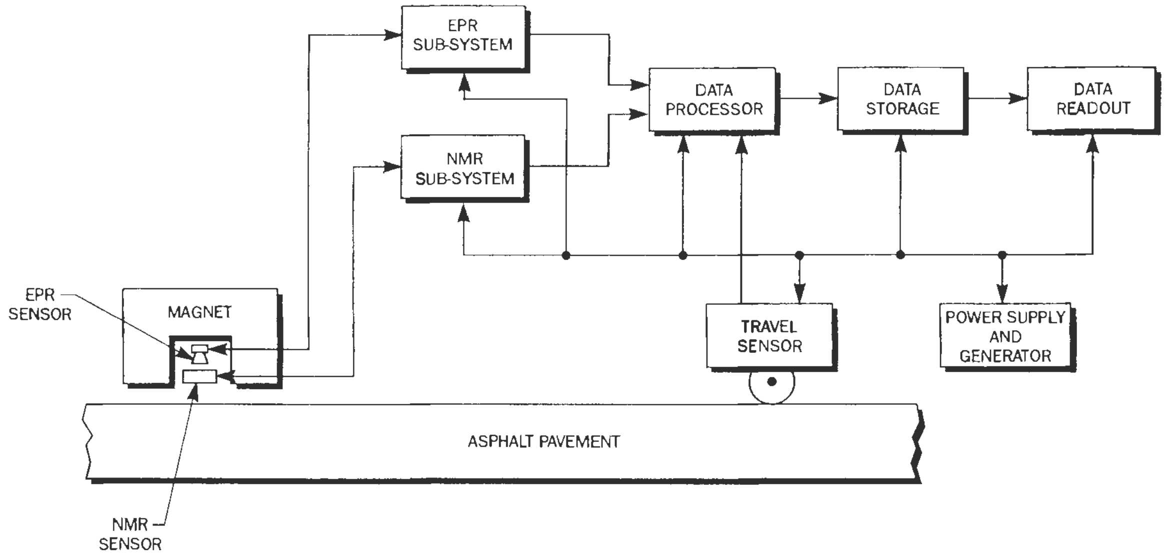


FIGURE 2 MR system for in situ asphalt inspection.

evaluate the technology and system performance over a variety of asphalt concrete roadways.

Conclusions from the IDEA project efforts are as follows:

1. Useful HTNMR data can be obtained from all asphalts.
2. The signal amplitude and NMR time constants T_1 and T_2 vary from asphalt type asphalt to another.
3. The T_1 and T_2 data correlate with the viscosity and penetration of the different neat asphalts.
4. T_1 is decreased by paramagnetic, particularly vanadium, and ferromagnetic constituents in asphalt.
5. The removal of the volatiles affects the spin-spin, T_2, relaxation time of all the neat asphalts.
6. Oxidation of the neat asphalts to simulate accelerated aging affects both T_1 and T_2. $T_{1\rho}$ provides the most consistent indication of oxidation aging. Oxidation over longer periods is needed to reach equilibrium.
7. The effects of oxidation aging are rapidly measured by HTNMR in a non-intrusive manner.
8. The T_1 of the asphalts is amenable to in situ HTNMR measurements from a moving vehicle.
9. EPR can provide a non-contacting, non-intrusive measure of the paramagnetic (vanadium and manganese) and ferromagnetic (iron) compounds in asphalt and other data.
10. Mixtures of asphalt and aggregates may introduce bonding effects and constituents (paramagnetic and ferromagnetic) that affect the HTNMR relaxation times. Additional studies are needed in this area.
11. In situ asphalt measure ments have been found feasible, but improved apparatus is needed to increase the sensitivity to the rapidly decaying, short T_2 component of the asphalt pavement NMR signal.
12. The recommended mobile inspection system for asphalt inspection includes optimized HTNMR and EPR subsystems in an integrated configuration with automated data acquisition and processing. The system is trailer-mounted with an integral engine generator to provide the required electrical power. The system is suitable for acquiring asphalt data while stationary or in motion at slow speeds (3 to 6 mph).

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The IDEA project has shown correlation between the aging of asphalt pavement and MR data that is amenable to non-contact, in situ measurement from a moving vehicle. The conceptual design and specifications for a mobile inspection system based on these technologies have been developed. The system, if assembled and evaluated over a wide variety of asphalt pavement roadways, would provide a potential for in situ determination of asphalt aging condition, moisture content, and other pertinent asphalt properties.

REFERENCES

1. *Distress Identification Manual for the Long-Term Pavement Performance Studies.* SHRP-P-338, May 1993.
2. F.N. Finn. *Asphalt Properties and Relationship to Asphalt Performance: Literature Review.* SHRP-A-314, May 1990.

3. C.A. Bell. *Summary Report on Aging of Asphalt Aggregate Systems.* SHRP-A-305, Nov. 1989.

4. S.C.S. Rao Tangella. *Summary Report on Fatigue Response of Asphalt Mixture.* SHRP-A-312, June 1990.

5. T.S. Vinson. *Summary Report on Low Temperature and Thermal Fatigue Cracking.* SHRP-A-306, June 1989.

6. R.L. Terrell and J.W. Shute. *Summary Report on Water Sensitivity.* SHRP-A-304, Nov. 1989.

EXCOGITATED COMPOSITE MULTIFUNCTIONAL LAYER FOR PAVEMENT SYSTEMS

NCHRP-IDEA Project 6[1]

Barry J. Dempsey[2]
University of Illinois, Urbana-Champaign

IDEA PRODUCT

An innovative excogitated composite multifunctional (ECM) layer will provide for design and construction of pavements with improved performance. The ECM layer (see Figure 1) is three-dimensional and will satisfy multiple functions in the pavement system by providing for subbase layer–subgrade separation, subbase shear strength, subbase tensile strength, drainage, and protection of the subgrade from surface infiltration.

CONCEPT AND INNOVATION

The ECM layer is a bold, innovative concept for pavement design and construction and should provide significant improvement in pavement performance while adding little to pavement cost. The ECM layer has the traits of rapid deployment, easy construction, portability, strength, and durability. Because it is flexible, the ECM layer will be taken to the construction site in a roll and placed by methods similar to those for placing geotextiles. Placement costs for the ECM layer are expected to be minimal.

The ECM layer is expected to be highly compatible with open-graded aggregate subbases since it will act as a separation layer and provide improved shear to the subbase. It will eliminate the need for a geotextile filter layer or granular filter layer between the subgrade and the open-graded subbase. It is also believed that the ECM layer concept can be used to decrease reflective cracking in asphalt concrete overlays.

IDEA PROJECT INVESTIGATION AND PROGRESS

The main objective of the IDEA project was to develop, fabricate, and evaluate one or more innovative ECM lay-

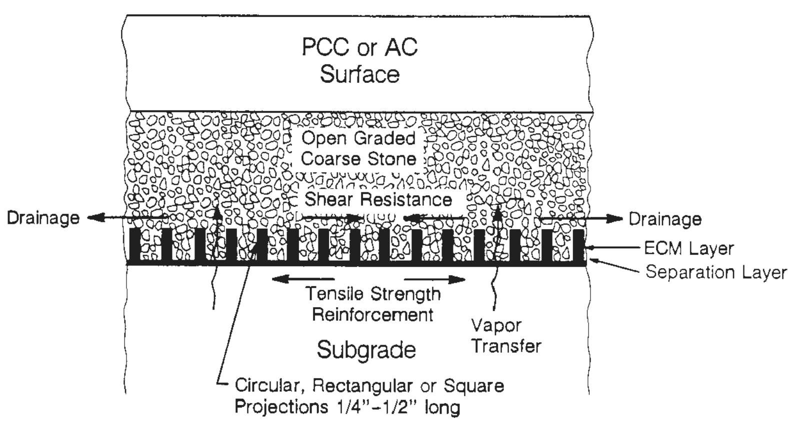


FIGURE 1 ECM layer concept and functions.

[1]The IDEA project started in May 1993 and will be completed by February 1995.
[2]Professor, Department of Civil Engineering.

ers for pavement systems. Research was conducted in the design and selection of materials that would satisfy the geometry and multifunctional requirements of the ECM layer in a pavement system. Major emphasis was placed on the development of lightweight and strong materials that can easily be deployed into rapid and economical pavement construction using available construction equipment. Both natural and synthetic materials were investigated for use in the ECM layer.

The major requirement of the ECM layer is to satisfy multiple pavement performance requirements by providing lateral drainage, subgrade protection and separation, tensile layer strength, and shear resistance in an aggregate subbase. To accomplish these multifunctional requirements, the development and evaluation of a three-dimensional material were emphasized.

This study used finite element procedures to define relationships between the ECM layer geometry, load, and material property requirements. The major finite element program used for this task is ILLI-PAVE (*1*). The ILLI-PAVE program can model composite designs with different numbers of layers, different ordering of layers, different layer properties, and a variety of other material characterizations. Once material properties were defined using ILLI-PAVE, the ECM layer was fabricated and evaluated in the laboratory to determine if it met the required performance criteria.

On the basis of initial ECM layer evaluations, a new improved ECM layer has been developed to meet the criteria necessary for substantially improved pavement performance.

Materials Selection and Evaluation of ECM Layer

Numerous materials, both synthetic and natural, were evaluated for use in the ECM layer for pavement systems. Materials properties were rated with both standard and non-standard index test methods. Index tests were employed to compare material properties rather than evaluating performance behavior. The index tests performed on the prospective materials were utilized to isolate and compare specific material properties that were important to development of the ECM layer.

A broad range of wide strip tensile strength data (ASTM D4595) for this project was available from other studies. Considerable strength data was also available for various geosynthetics in the *Geotechnical Fabrics Report Specifiers Guide* (*2*).

A series of water vapor transmission tests was conducted following ASTM E96 procedures to identify a geosynthetic to meet the ECM layer vapor conductivity requirements. A non-woven geotextile, MERGE, and a geomembrane-geotextile composite, PETROPAVE MB (both manufactured by Phillips Fibers Corporation), were compared in these tests. The PETROPAVE MB was modified by needle punching a specified number of holes in order to enhance the vapor conductivity. Study results indicated that the MERGE geotextile provided greater vapor transmission than the PETROPAVE MB, even with needle holes added. The MERGE geotextile also easily met the requirements of the ECM layer for water vapor transmission. The ECM layer must allow subgrade moisture in the vapor state to pass upward to prevent a high water content layer from occurring immediately under the geocomposite.

The shear strength and tensile strength of various materials were examined for the reinforcement component of the ECM layer. Two prototype ECM layers (designated as ECM layer and New Improved ECM layer) were constructed and tested for comparison with generally used materials. The direct shear strength comparisons were made in the lower 1 inch of an open-graded aggregate base course material placed on the subgrade soil, a woven geotextile (SUPAC 6WS), a geogrid (Tensor BX-1200), an ECM layer, and a New Improved ECM layer.

Figure 2 shows that both the ECM layer and New Improved ECM layer provided greater shear resistance in the lower portion of the open-graded base course aggregate than the other materials. The improved shear strength is especially evident in the New Improved ECM layer at the higher normal stresses. This is caused by the higher polymer stiffness and more strain-resistant geotextile used in the New Improved ECM layer.

In order to evaluate the reinforcement properties of the ECM layers, the tensile strength properties were determined using the guidelines of ASTM D4595 for wide strip test sections. Figure 3 shows the wide strip tensile test results for a geogrid, ECM layer, and New Improved ECM layer. The letters M and X in the legend refer to the orientation of the materials during the test, with M being the machine direction and X being the cross machine direction. Although the tensile strength of the geogrid was mobilized before that of the ECM reinforcement layers and had higher peak tensile stress values in both orientations, it is believed that the ECM layer tensile strength is well within acceptable limits. The letter F in the legend indicates that a bonded geotextile was part of the ECM layer. The New Improved ECM layer showed improved tensile strength properties over the original ECM layer at low strain values; these strength properties satisfy the reinforcement need in granular base courses.

A modified California bearing ratio (CBR) test was used to compare granular base course reinforcement and

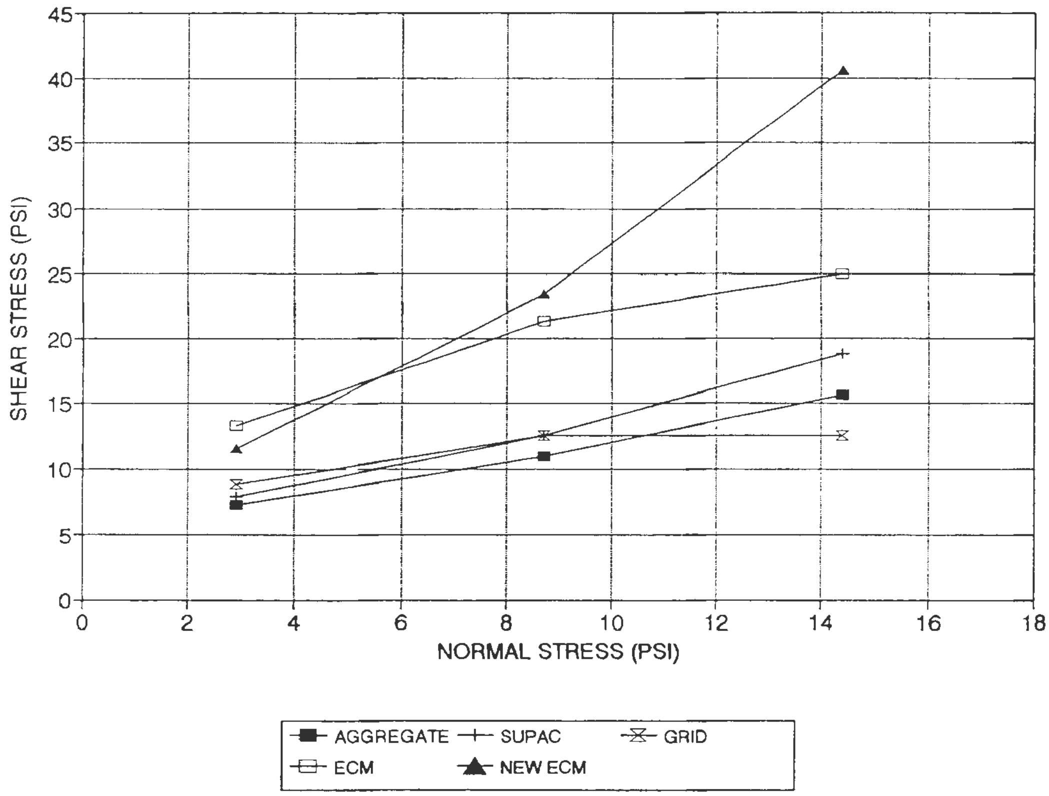


FIGURE 2 Direct shear stress results between aggregate base and test materials.

shear influence of the ECM layer with base courses with no geosynthetic (control) and geogrid (Tensor BX-1200). All materials were tested in a 12x12x12-inch steel container using varying thicknesses of open-graded crushed stone (6 inch and 8 inch) over stiff crumb rubber pads used to model a very soft subgrade. Loads were applied to the aggregate surface through a CBR piston at a rate of0.1 inch/minute. Figures 4 and 5 show the results of these tests. The New Improved ECM layer provided substantial strength improvement in the open-graded crushed stone material in all the tests when compared with no geosynthetic. This layer performed much better than the geogrid in all tests as well.

The results of these tests indicate that the New Improved ECM layer demonstrates the material properties necessary to perform as a multifunctional layer in a pavement system. The magnitude of the loads in Figures 4 and 5 are dependent on both the shear properties and the tensile strength of the ECM layer. It is the three-dimensional properties of the ECM layer that provide excellent shear properties that supplement the reinforcement properties.

A large-scale evaluation study of the New Improved ECM layer is being conducted. A 6-feet x 6-feet x 40-inch-deep test cell has been constructed for use in evaluating the ECM layer under dynamic loading conditions. A commercial Moscow, Missouri, brick clay (AASHTO A-7-6) was compacted in the test cell to a depth of 30 inches at a dry density of 113 pcf and at an optimum water content of 15%. A water table is maintained at the bottom of the 30 inches of clay fill.

A control test is being conducted on 6 inches of open-graded crushed stone placed over a nonwoven geotextile layer on top of the subgrade soil. When completed, the crushed stone and geotextile will be removed and the new improved ECM layer will be placed on the subgrade. A 6-inch layer of open-graded crushed stone will then be placed over the ECM layer. Both the control section and ECM section will be loaded dynamically through a 6-inch-diameter steel plate placed on the crushed stone base. The permanent and dynamic deformations will be measured in relation to the number of load applications. It is believed that this testing and evaluation program will provide important data to support the superior

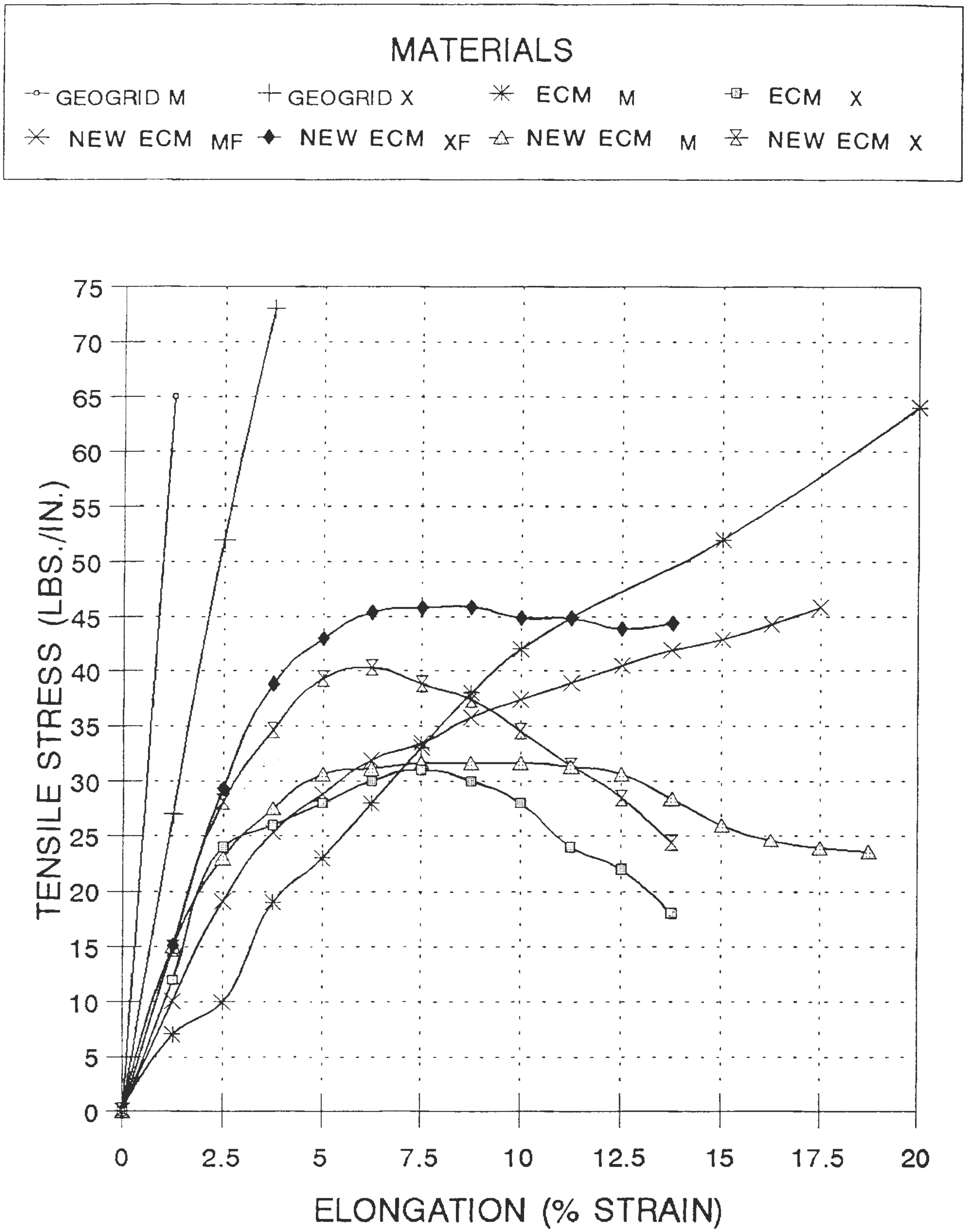


FIGURE 3 Wide strip tensile strength results (loading rate = 0.5 inch/minute).

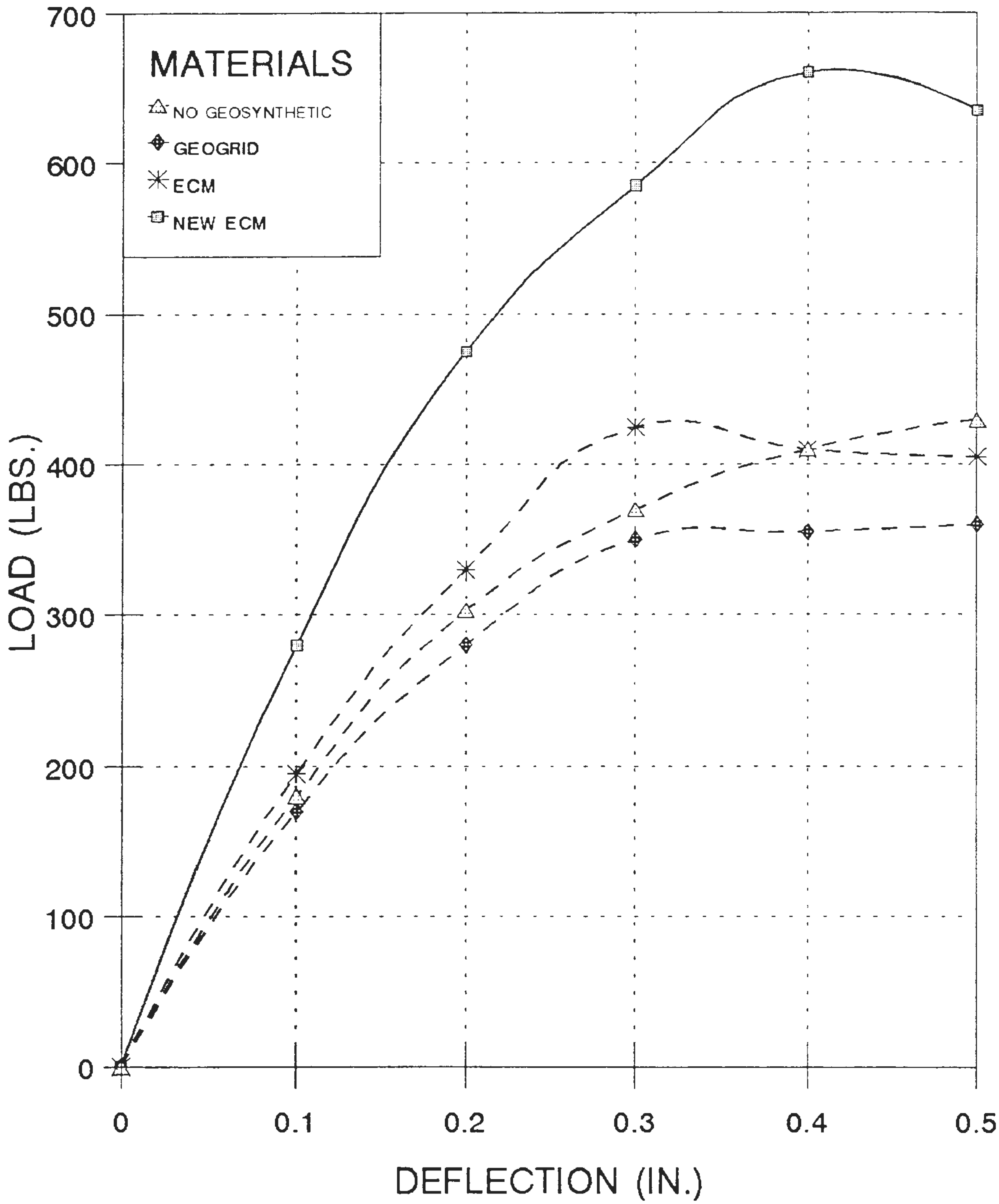


FIGURE 4 Load-deflection relationship for 6 inches of CA-16.

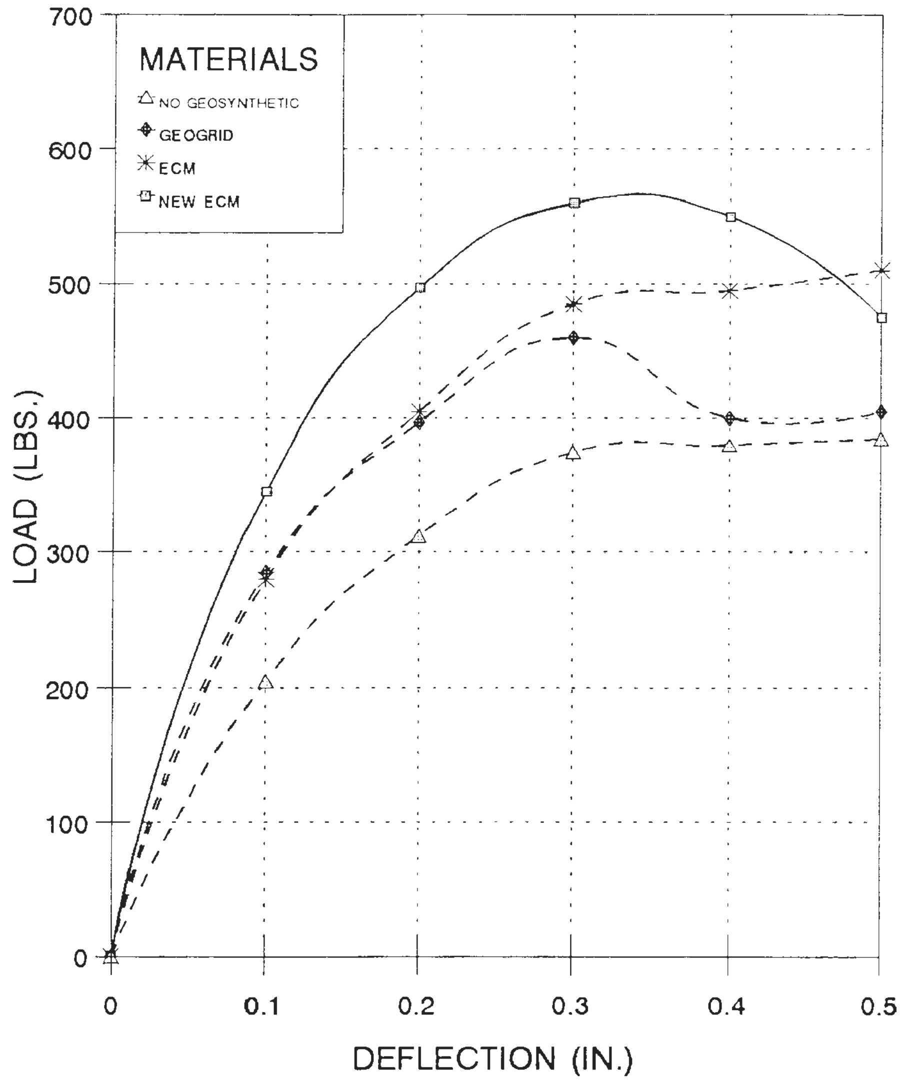


FIGURE 5 Load-deflection relationship for 8 inches of CA-16.

performance qualities of the ECM layer as well as an indication of its field performance.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

Upon successful completion of this project, construction of one or more field test sections during the summer of 1995 is proposed. The Illinois Department of Transportation has expressed interest in cooperating in such a field test. A manufacturer of the New Improved ECM layer has been identified, and an adequate volume of materials can be produced to satisfy test section studies in 1995.

The ECM layer concept is likely to find widespread use in all types of construction at the local, state, and national levels. The potential for using the IDEA product beneath railroad ballast will also be tested.

REFERENCES

1. M.R. Thompson. *ILLI-PAVE Users Manual.* Department of Civil Engineering, University of Illinois, Urbana-Champaign, 1992.
2. *Geotechnical Fabrics Report.* 1993 Specifiers Guide. St. Paul, Minn., 1993.

STRATEGY FOR COATING STEEL WITHOUT STRINGENT BLASTING REGULATIONS

NCHRP-IDEA Project 7[1]

Simon Boocock
Steel Structures Painting Council, Pittsburgh, Pennsylvania

IDEA PRODUCT

An environmentally safe process for applying durable protective paint coating on previously painted steel structures without the need for thorough surface cleaning and preparation is presented. The IDEA project combines two recently developed technologies to provide an engineered system that will allow highway agencies to protect previously painted structures, particularly those with lead-based alkyd paint, without environmentally damaging surface preparation and with reducing emissions of volatile organic compounds (VOC). The two technologies are a penetrating primer with fractured microspheres for optimized topcoat adhesion and zero-VOC plastic thermal spray polymer or liquid applied topcoats. Previously used in marine application to permit application of thermal spray metallic antifouling to composite boat hulls, this new IDEA product is intended for application to major bridge structures.

CONCEPT AND INNOVATION

The concept applies the following new developments for recoating old painted steel structures:

- Surface-tolerant high-penetration primers: These low-or zero-VOC epoxy primers are capable of penetrating porous rust, retained scale, and brittle paint and are insensitive to retained surface contaminants such as chloride.
- Interlocking of primer and topcoat by embedding hollow glass fly ash microspheres in the primer. Fracturing these spheres provides a surface profile that "locks in" the top coat and ensures a strong bond between the primer and the top coat.
- Low-temperature thermal spray to apply a dense topcoat of environmentally stable zero-VOC polymers in liquid form.

The approach is illustrated in Figure 1. This technology has been used on a commercial scale on marine vessels prior to metallizing, but it has never been applied to the protection of steel structures with organic coatings.

Thorough blast cleaning is generally required before protective coating is applied to structural steel by painting or thermal spraying. This is necessary but undesirable in terms of cost, environmental contamination, and quality control when the steel structure has previously been coated with lead-based paint. The proposed technology, if successful, will significantly reduce surface preparation requirements and provide an economical long-term protection.

IDEA PROJECT INVESTIGATION AND PROGRESS

The project is being carried out in two stages.

Stage 1: Process Feasibility, Reliability, and Optimization

Work in Stage 1 consisted of determining (a) the optimum amount of glass microspheres to promote strong adhesion in the penetrating primer sealer, (b) characteristics of film coating, and (c) compatibility of topcoat polymer with penetrating primer and aged lead-based alkyd coatings.

Two commercially available penetrating sealers (Pre-Prime and Rustbond, both thin film epoxy, 100% solid) specified for use on surfaces with rust or aged paint coatings were selected for this study.

Optimum Loading of Glass Microspheres

Tests to determine the optimum loading level of glass microspheres showed best results at epoxy primer/filler ratios of 4:4 or 4:5 in terms of dense packing of spheres, ability to withstand cracking of spheres to create keying surface and adhesion to the surface. Consequently, the epoxy primer and filler were mixed in a 4:5 ratio for all subsequent tests.

[1]The IDEA project started in April 1994 and will be completed by March 1995. The IDEA project advisor is Alfred Beitelman, Construction Engineering Research Laboratory, Champaign, Illinois.

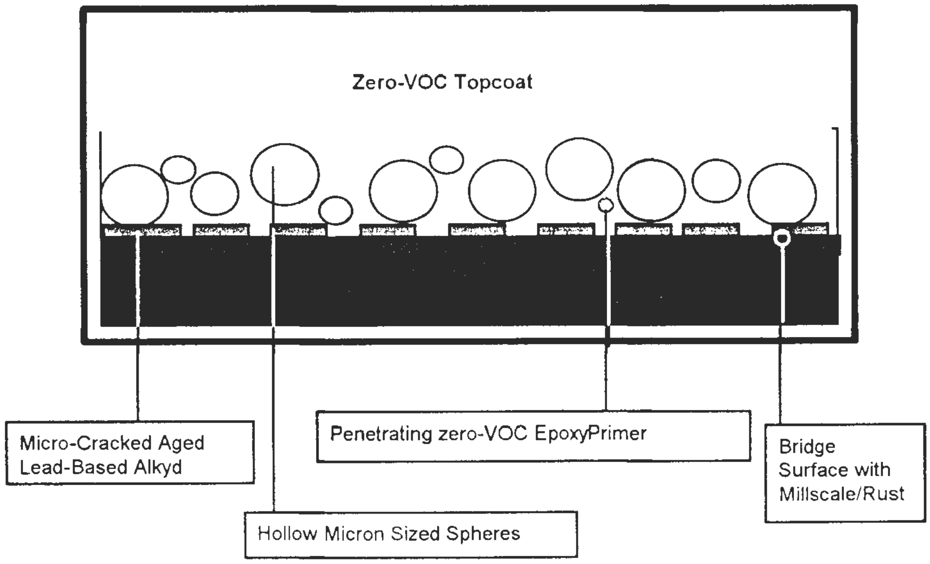


FIGURE 1 Product applied to bridge use.

Film Characteristics

The second task determined the integrity of coatings of zero-VOC liquid polymers applied by thermal spray to the primer-treated surface. Specimens for both aged painted and blast-cleaned steel surfaces were evaluated. A set of each of these specimens was also subjected to secondary surface preparation by sweep blasting to break the glass spheres. For the thermal spray process, both "clear" and pigmented polymers were used for topcoats.

The film integrity was determined by micrographic examination and by holiday detection test. The adhesion was determined by ASTM tests D4541 (pull-off strength measurements) and D3325 (X-cut adhesion by tape pull-off).

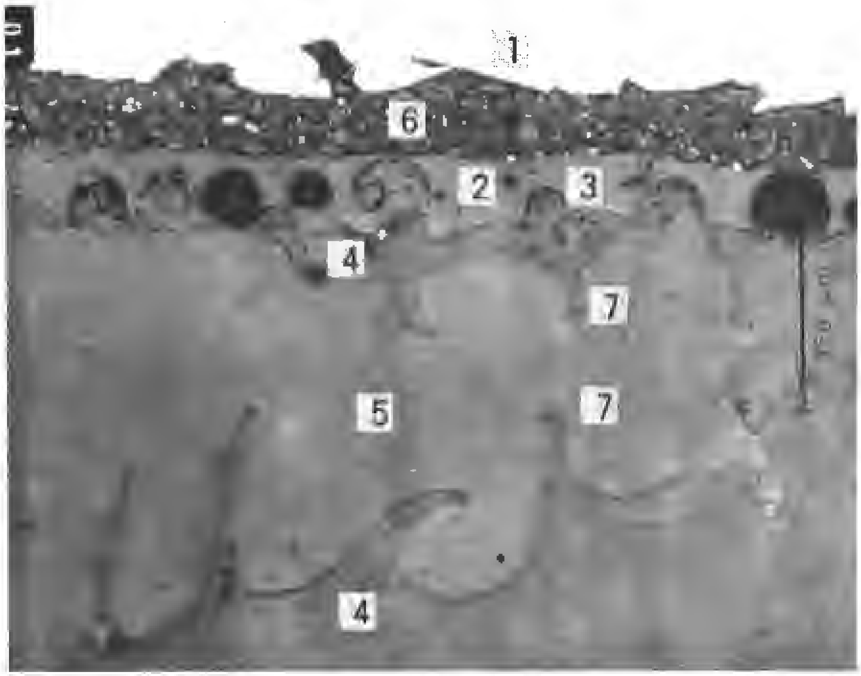
Photomicrographic Examination All combinations of primers and thermal spray topcoats provided some indication of penetration of the sprayed polymer into the hollows of the broken spheres embedded in the primer. This is the key to enhanced topcoat bonding to the primer. Inspection of partially peeled topcoats showed "necking" of the polymer at sites of the anchoring spheres, providing some verification of this enhanced performance (see Figure 2). Photomicrographs of the coated surface revealed that not all recesses in the cracked microspheres became filled with thermally sprayed polymer; however, this did not harm the physical integrity of the applied coating, as shown by holiday detection and adhesion test measurements.

Holiday Detection Test A simple "bird dog" holiday detector was used to assess the film integrity and homogeneity. In no instance were voids penetrating to the metal surface observed with any of the prepared samples, indicating the viability of the process for producing uniform, defect-free films. However, another set of panels, with sphere loaded penetrating primer on the bare steel, failed the holiday detection test. This is not surprising, as the penetrating sealer forms a very thin film on the surface.

Adhesion Tests The ASTM D4541 adhesion data are interesting but difficult to interpret. An aluminum dolly is attached to the coated surface using epoxy glue. This is then pulled off using a portable Instrom-like machine. The pull-off value is read from a scale accurate within about 345 kPa (50 psi). The absence of any strong trend is an indicator that adhesion is not negatively affected by any one process or system variable examined at this stage.

The results from the samples applied to simple surfaces finished using liquid applied epoxy topcoat did not show failure points involving the primer. The pull-off value associated with each such failure is as high as or higher than that found for failure in the topcoat alone.

Tests were performed to determine the effectiveness of using glass microspheres in promoting adhesion. The glass spheres have been shown to promote adhesion in marine coating applications. Initial experimentation is under way to establish whether using glass spheres will enhance adhesion



1 = steel

2 = primer

3 = broken spheres filled w polymer

4 = Polymer topcoat

5 = mounting plastic

6 =old alkyd paint

7 = "necks" of polymer formed during peel

FIGURE 2 Polymer topcoat on epoxy primer with glass microspheres.

by comparing differences in adhesion between coatings in samples tested with and without spheres in the penetrating primer layer.

Compatibility of Topcoats with Penetrating Primers and Aged Alkyd Coatings

As part of the work involving penetrating primers, samples were prepared to which either a thermal spray polymer or liquid applied zero-VOC topcoat was applied. Test results did not indicate any detrimental effects on film integrity and adhesion characteristics, nor was any significant incompatibility between the topcoats and the penetrating primers noticed.

As part of the work on the use of thermal spray polymer topcoats, samples were prepared in which the initial surface was an aged alkyd coating. Again, test results showed no detrimental effects on film integrity and adhesion characteristics, and no significant incompatibility between the thermal spray polymers and aged alkyd coatings was observed.

The process, as examined and established in the preceding tests, was also considered to be useful for accelerated short-term testing of the specimens.

Stage 2: Laboratory and Field Evaluations

In the second stage, the optimized coating system and methodology will be evaluated in the laboratory using short-term accelerated testing. From this evaluation, the system will be further refined and optimized; limited field testing will follow.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The implementation of this new painting process on highway steel bridge structures will require trial testing in collaboration with state highway agencies. Old bridge structures with lead-pigmented alkyd paint would be best suited for testing of the coating concept.

CONSERVATION TRAFFIC CONTROL LOAD SWITCH

NCHRP-IDEA Project 8[1]

Gregory A. Filbrun, Paul Wiese, and Greg Winthrow
CLS Incorporated, Westerville, Ohio

IDEA PRODUCT

A new conservation traffic control load switch (CTCLS) has been developed. The CTCLS has been designed to prolong the life of the incandescent lamps used in traffic signals by a minimum of 4 times; depending upon the voltage set point selected by the U.S. Department of Transportation (USDOT), the CTCLS has the ability to extend the life of the lamp 8 to 10 times. The CTCLS also has the potential to conserve energy by constantly regulating the input voltage from the controller to the signal head and soft-starting or ramping up the in-rush current to eliminate the initial surge of current for each cycle. The CTCLS has a built in microprocessor fail-safe to revert the unit to a conventional load switch; this is the most critical aspect of the unit. This technology could have applications in temporary traffic signals, flashers, railroad crossings, arrow panels, and changeable message signs. The CTCLS meets all pertinent National Electrical Manufacturers Association (NEMA) Model 170, Model 200, and the Institute of Transportation Engineers (ITE) specifications and is fully programmable to meet other regional requirements (dependent upon the voltage regulation set point selected by the USDOT, a higher minimum rated lumens output lamp or bulb may be required).

CONCEPT AND INNOVATION

Conservation and soft-start technology were applied to create a multifaceted solid state CTCLS. The CTCLS extends the life of the traffic lamp by a minimum of four times and reduces maintenance expenditures. Estimates show that installing the CTCLS in 2 million signal heads nationwide would result in cost savings of about $180 million per year.

IDEA PROJECT INVESTIGATION AND PROGRESS

The IDEA project appears successful. The CTCLS lab test units are being shipped to participating departments of transportation (DOTs). The CTCLS is also undergoing independent NEMA testing. The investigator is currently receiving requests for test units, participation in this study, and spec sheets weekly from across the nation from DOTs, manufacturers, and distributors.

Technical Issues

A load switch that will gradually increase the voltage to the lamp over 80 milliseconds was developed. This timing is to eliminate the high surge of current to the filament coil, yet is fast enough so the difference in brightness cannot be detected by the human eye.

The CTCLS routes the initial alternating current (AC) common 120 line into a microcomputer containing a complex series of software algorithms to slow the current surge. The microcomputer controls the triac triggering to cut the sinusoidal wave input in both the positive and negative halves. The microcomputer constantly monitors the line voltage. If the line voltage falls below 102 volts, the circuitry conducts for the full AC cycle time. When the incoming AC voltage is above 102 volts, the triac circuit delays firing for a short period to allow a regulated 102 volts root mean square to be sent to the lamp. Since the ITE standard for lumen output is specified at 1750 lumens in the CTCLS's specifications, a 2450 minimum luminous output lamp will be required. This will allow for margin and meet ITE specifications.

Engineering Difficulties To Be Addressed

The essential engineering problems encountered in this investigation were to reduce the surge current while maintaining the standards for ITE lumens output and NEMA Models 170 and 200. The input isolation circuits and triac drivers are almost identical to existing standard NEMA Models 170 and 200 traffic control load switches in the field. The microprocessor with an eight-bit analog-to-digital input

---

[1]The IDEA project started in February 1994 and has been completed. The IDEA project advisor is Dwight Stevens, Iowa Department of Transportation.

controls all of the CTCLS's advanced technological functions, including a redundant converter fail-safe to a standard traffic control load switch in case of microprocessor failure. When an input is detected from the isolation circuits, the microprocessor starts a slow voltage ramp signal to the triac driver circuits.

Each AC cycle is programmed to have no direct current (DC) offset. To eliminate any DC imbalance to the AC input line, the exact number of cycles of the soft start will be controlled in the microprocessor's memory. As the softstart process is ending, the program calculates the final phase angle from the AC line input. In all cases the voltage to the lamp provides enough power to meet the ITE lumens standard.

The mechanical packaging is of the standard NEMA Model 170 and 200 traffic control load switches. All electronics are conformally coated with CONAP CE1170 using multiple thin coats to obtain a final coating thickness of 0.0035 to 0.0045 inches in a similar manner to existing units, per ANSI/IPC SN-782-1987 Class 2 standards for exceptibility of CB assemblies. The connector and housing are exactly the same as existing units to ensure that no retrofit will be required.

Cooperative Arrangements with State and Municipal Research Facilities and Potential Users

One hundred prototype units are being produced and will be sent to each of the following signal labs for lab/bench testing:

- New York DOT;
- California DOT;
- Florida DOT;
- California DOT, Los Angeles;
- West Virginia DOT;
- South Carolina DOT;
- Ohio DOT, Columbus;
- Ohio DOT, Westerville;
- City of Chicago, DOT;
- New Jersey DOT, Monmouth County;
- Virginia DOT;
- Texas DOT;
- Idaho DOT; and
- Calgary, Alberta, Canada DOT.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

Manufacturing and sales relationships with major manufacturers and distributors of traffic control load switches are being established. Foreign countries where interest in the CTCLS has been expressed include Canada (all provinces), Mexico, Hong Kong, South Korea, Northern Mariana Islands, Turkey, Virgin Islands, Mexico, and Germany.

Proposed retail pricing for the CTCLS is $119.00 per unit; with a trade-in rebate of $30.00 for refitting, the price will be $89.00, which represents an average of a 12-month payback. The investigator is working with numerous organizations such as the Innovations Group of Tampa, Florida. This organization maintains direct contact with at least 340 city and municipal managers, which provides direct access to the "buyer/users" of the CTCLS. Sales presentations will be prepared to include letters of introduction, videos, worksheets, break-even worksheets, and phase-in discounts.

The marketing strategy incorporates plans to sell the CTCLS through several channels including direct sales, manufacturers' representatives, distributors, catalogs, joint marketing relationships, original equipment manufacturers, and international distribution. Primary focal points during each sales call and presentation will be lead generation, lead referrals and follow-up systems and letters of introduction. The information gathered will be disseminated continually to the buyers and sales force.

CORROSION-RESISTANT STEEL REINFORCING BARS

NCHRP-IDEA Project 9[1]

David Darwin,[2] Carl E. Locke, Jr.,[3] Matthew R. Senecal,[4] Jeffrey L. Smith,[4] and Shawn M. Schwensen[4]
University of Kansas, Lawrence

IDEA PRODUCT

Concrete reinforcing steel with improved corrosion-resistant properties is evaluated. The development of such a steel is based on TATA Steel Company research results from India that provide evidence that specific microalloying and rolling procedures can enhance the corrosion resistance of steel reinforcing bars. Using copper, chromium, and phosphorous as alloying elements and heat treating the steel following the rolling process appear to increase corrosion resistance. The key goal of the IDEA study is to apply the concept and evaluate corrosion resistance under realistic conditions in concrete, specifically in regions in which reinforced concrete is subjected to chlorides. If the added corrosion resistance of the new steel is demonstrated, its use will greatly enhance the durability and life expectancy of transportation structures, with special emphasis on highway bridges in areas in which deicing chemicals are used and in coastal areas in which the structures are subjected to high salt concentrations—environments in which corrosion protection is essential.

The corrosion of reinforcing steel in highway structures results in maintenance and replacement costs in the United States that are measured in billions of dollars; it is the single largest problem in the durability of highway bridges in the United States.

CONCEPT AND INNOVATION

The new reinforcing steel in this IDEA evaluation differs from steel used in standard U.S. practice in a number of ways. Additional alloying elements—copper, chromium, and phosphorous—are used along with a special heat treatment to provide the corrosion-resistant properties of the steel. The bars possess lower carbon content than is usual in U.S. practice, and the phosphorous content exceeds that allowed in ASTM specifications. The bars are quenched and tempered immediately following the rolling operation, a step that places the exterior of the bars in compression. The apparent corrosion-resisting mechanisms include the formation of a corrosion-retarding layer of copper chloride–copper hydroxide at the steel surface in the presence of chlorides; the formation of phosphorous oxides, which serve as corrosion inhibitors; the formation of iron-chromium oxide at the steel surface, which is a poor conductor and thus reduces the corrosion rate; and the reduction of microfractures in the surface from the rolling operation due to the quenching and tempering process. The corrosion products that form are much denser than for normal reinforcing steel, which further reduces the availability of oxygen and water at the steel surface, and the reduced microfracturing further reduces the surface area available for corrosion.

The specific technical issue addressed in this study involves not the ability of the steel to be more corrosion-resistant in the atmosphere, which seems to have been amply established in earlier studies, but to demonstrate its corrosion resistance when embedded in concrete, where the environment is much different. The distinction is important since many materials exhibit superior corrosion resistance in the atmosphere but perform poorly in concrete. Reinforcing steel will not corrode in uncontaminated portland cement concrete due to the high pH environment and the calcium hydroxide that precipitates at the steel surface. The pore solution in portland cement concrete has a pH of about 13.8 and contains a mixture of potassium and sodium hydroxides. Steel in this environment is passive and remains in a noncorrosive condition unless contaminants such as chloride ions or carbon dioxide intrude. To evaluate the new steel for practical application requires testing in an

[1]The IDEA project started in June 1994 and will be completed by May 1995. The IDEA project advisor is Douglas Burke, Naval Facilities Engineering Service Center, Port Hueneme, California.
[2]Professor, Department of Civil Engineering.
[3]Professor, Department of Chemical and Petroleum Engineering.
[4]Graduate Student, Department of Civil Engineering.

environment in which the steel is in contact with hydrated cement paste (in mortar or concrete) and subjected to chlorides so that macrocorrosion cells can develop.

IDEA PROJECT INVESTIGATION AND PROGRESS

The IDEA project is carried out in two stages. Two general categories of test specimen have been developed to resolve the key technical issues. Small test specimens, with low cover over the reinforcing steel, are used to obtain a rapid measure of the corrosion of the reinforcing steel; larger test specimens, with realistic concrete covers, are used to evaluate the practical performance of the reinforcing steel over extended periods of time. The latter test specimens are the only types currently accepted in U.S. practice.

Work during Stage 1 of the project has involved (a) the performance of short-term tests for rapid corrosion potential and time to corrosion using small specimens, and (b) the design and initiation of long-term time-to-corrosion tests on larger specimens. The tests involve the side-by-side evaluation of conventional reinforcing steel and the new steel in both hot-rolled and heat-treated (Thermex) form. In addition, the corrosion-resistant Thermex and hot-rolled bars are also tested in specimens containing an inorganic (calcium nitrite) or organic corrosion inhibitor. The short-term tests currently indicate that the new reinforcing steel, with both the new alloying elements and heat treatment, consistently provides improved corrosion protection. However, practical application of the steel must await the results of the long-term tests, which will become available during Stage 2 of the project.

Rapid Corrosion Potential and Time-to-Corrosion Tests

The tests used for rapid evaluation of corrosion are based on earlier work at the under the Strategic Highway Research Program (SHRP). The tests allow very rapid evaluation of both the corrosion potential and the formation of a corrosion macrocell for reinforcement. The basic test specimen (Figure 1) consists of a length of reinforcing bar embedded in a cylinder of mortar with a water-cement ratio of 0.5. The contact surface between the mortar and the bar simulates the contact obtained between concrete and reinforcing bars in actual structures due to the use of both a realistic water-cement ratio (slightly higher than normal to provide for the earlier initiation of corrosion) and a realistic sand-cement ratio.

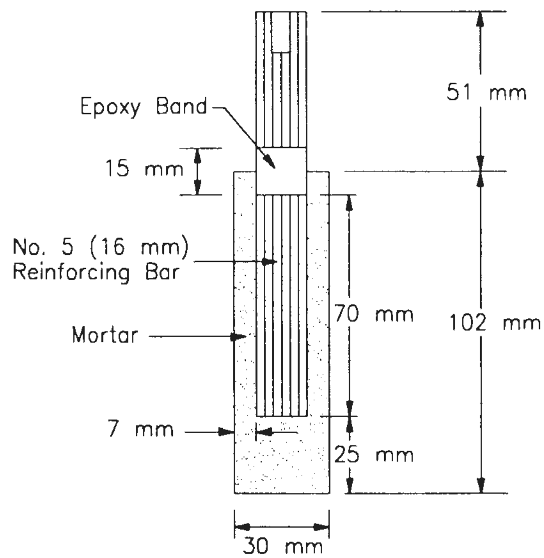


FIGURE 1 Cross section of test specimen used for rapid corrosion and time to corrosion tests.

The corrosion potential test (Figure 2) requires two plastic containers. The test specimen is placed in a 5-liter container along with crushed mortar fill and a simulated pore solution containing a preselected concentration of sodium chloride. A standard calomel reference electrode is placed in a separate container along with a saturated potassium chloride solution. The two containers are connected by a salt bridge, and the potential (voltage) of the steel with respect to the calomel electrode is measured at selected time intervals using a digital voltmeter. This is called the corrosion potential of the steel.

The mortar fill consists of the same mixture as used in the test specimen. The fill is used primarily to serve as a buffer and to help simulate the relative amount of cementitious material that exists in an actual structure. The simulated pore solution (a mixture of sodium

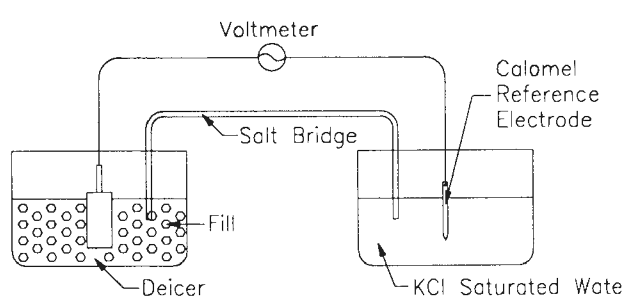


FIGURE 2 Schematic of corrosion potential test configuration.

hydroxide and potassium hydroxide) represents the liquid in the saturated pores and capillaries in concrete. With the mortar fill, it helps establish a realistic environment to measure the progress of corrosion of reinforcing steel. The salt bridge allows for the completion of the corrosion cell at the time that the voltage difference, "corrosion potential," is measured.

To obtain a rapid measure of the degree of corrosion that occurs through the formation of a macrocell, the corrosion potential test is modified by adding an additional test specimen to the container with the pore solution containing sodium chloride. Four additional standard specimens surrounded by mortar fill and immersed in simulated pore solution (with no chlorides added) are placed in a second container. The test specimens in the pore solution containing sodium chloride (anode) are electrically connected through a single 10 ohm resistor to the four specimens in the simulated pore solution (cathode). The macrocell test specimen is completed by a salt bridge that connects the liquid in the two containers. Air (scrubbed to remove CO_2) is bubbled into the liquid surrounding the cathode to ensure an adequate supply of oxygen. The rate of corrosion can be measured by measuring the voltage drop across the resistor. In addition to the basic tests, the corrosion-resistant Thermex and hot-rolled bars are also tested in mortar containing calcium nitrite or an organic corrosion inhibitor.

Bench Scale Time-to-Corrosion Tests

Two widely accepted long-term tests will be used to determine the rate of corrosion of reinforcing steel in both uncracked and cracked concrete. The specimens for these tests, all of which are now under way, were fabricated using a water-cement ratio of 0.5 and 19-mm (3/4-inch) maximum size aggregate.

The first test specimen, the southern exposure (SE) specimen, consists of a small slab containing two mats of reinforcing steel (Figure 3). The top mat consists of two bars; the bottom mat consists of four bars. The mats are electrically connected across a 10 ohm resistor. The sides of the concrete are sealed with epoxy, and a dam is placed around the edge of the top surface. A 15 percent sodium chloride solution is placed inside the dam, allowing the chlorides to penetrate into the concrete. The slabs are subjected to a 7-day alternate ponding and drying regime, with ponding at 21°C (70°F) for 4 days and drying at 38°C (100°F) for 3 days. The test provides a very severe corrosion environment, and it is generally believed that it can simulate 15-20 years of exposure for marine structures and 30-40 years of exposure for bridges within a 48-week period.

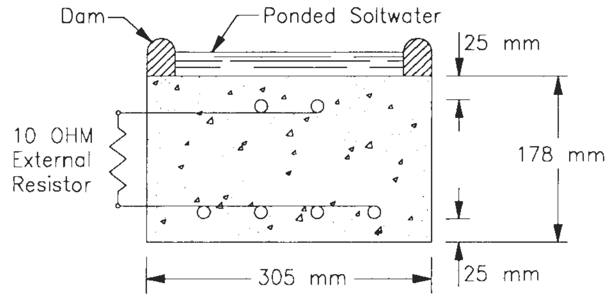


FIGURE 3 Schematic of SE test specimen (254 mm = 1 inch).

The second test specimen, the cracked-beam specimen, is half the width of the SE specimen and has one bar on top and two bars on the bottom. After curing of the concrete, the beam is cracked to provide a preselected crack width on the upper surface. A dam is placed on the specimen in a manner similar to that used for the SE specimen. Like the SE specimen, the cracked-beam specimen is subjected to cycles of wetting and drying with a 15 percent sodium chloride solution, and the tests are carried out for 48 weeks.

Results

Figure 4 shows typical preliminary results from the relationships between corrosion rate and time for the macrocell tests for specimens immersed in sodium chloride solutions. The corrosion rate is expressed as micrometers per year (25.4 mm = 0.001 in.). The test results to date illustrate significant variation in the performance of the regular hot-rolled (H), regular Thermex (T), and corrosion-resistant hot-rolled (CRSH) steel but consistently superior performance by the corrosion-resistant Thermex (CRST) steel.

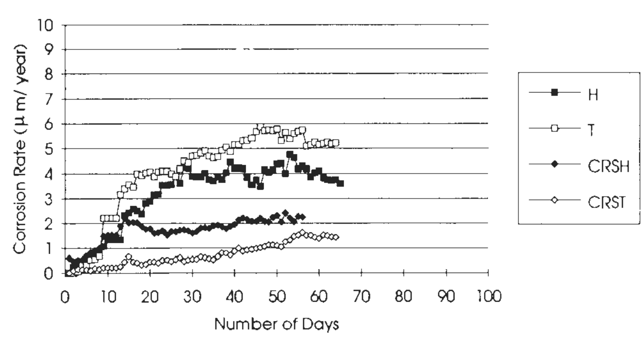


FIGURE 4 Corrosion rate versus time for macrocell test specimens subjected to a 0.4m ion solution of NaCl.

In contrast to the macrocell tests, the rapid corrosion potential tests using a 15 percent sodium chloride solution have exhibited no real difference between the four types of steel. All four types reached a corrosion potential (note, no macrocell corrosion occurs in these tests) with respect to a standard calomel electrode between -0.5 and -0.6 volts, in most cases, within 5 days. The lack of difference in corrosion potential indicates that the nature of the difference in the corrosion resistance of CRST and the other steels may be tied to differences in the corrosion products and surface condition of the bars.

In the long-term tests, no clear difference in response is discernible during the first 16 weeks of the study. Ultimately, however, the corrosion resistance of the new steel must be established on the basis of the longer time-to-corrosion tests.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

If the results prove successful, implementation plans include fabrication and testing of rebars produced with different percentages of alloying elements, followed by comparative corrosion testing. The additional project work is expected to be funded by Florida Steel, the U.S. producer and a supporter of the current research. State departments of transportation will be contacted for potential application of the new steel in reinforced concrete bridge decks.

METALLIC COATING FOR CORROSION PROTECTION OF STEEL REBARS

NCHRP-IDEA Project 10[1]

Angel Sanjuro, Kai Lau, David Lowe, Palitha Jayaweera, and Gopala Krishnan
SRI International, Menlo Park, California

IDEA PRODUCT

A low-cost gaseous coating technique to deposit silicon-titanium (Si-Ti) coating (corrosion-resistant metals) on steel rebars for use in reinforced concrete was examined. The Si-Ti coating on the steel rebar is expected to perform multiple protective functions. First, it will protect the steel rebar during storage even in open humid environments such as yards. Second, it will protect the steel after it is embedded in the concrete. This coating is particularly effective in preventing corrosion in chloride environments. Finally, the native Si and Ti oxides formed should result in good adherence and compatibility with the cement and aggregate chemistry.

CONCEPT AND INNOVATION

This project investigates a novel disposition technique that uses powders of Si and Ti metals to coat steel. Si and Ti powders are loaded in a fluidized bed reactor that has very high rate of heat and mass transfer. Si and Ti are transferred to the steel surface; Si has tendency to diffuse into the steel and Ti, to stay on the surface. This type of coating results in a tenfold decrease in the corrosion rate.

IDEA PROJECT INVESTIGATION AND PROGRESS

Iron-silicon (Fe-Si) coatings and iron-silicon-titanium (Fe-Si-Ti) coatings were deposited on steel rebars using a simple fluidized bed reactor 75 mm in internal diameter and 200 mm high. A scaled-up version of the reactor capable of coating 3-foot-long (0.9-m) rebars is being completed.

In a previous SHRP-IDEA concept investigation, steel samples were coated with only Si as the coating agent at temperatures from 400-650°C. Coating rates were relatively fast, reaching 1 mm/minute at the highest temperatures. Thinner coatings (less than 10 mm) were obtained at the lower deposition temperatures (<550°C) and shorter deposition times (<30 minutes). They were compact, adherent, and protective, as they did not tarnish when exposed to humid air. The absence of any observed changes in the microstructure of the underlying steel substrates, even at the highest coating temperature, indicated that the coating had no effect on the structural properties of the steel rebars. The corrosion rates of the Si-coated rebars were about half of the rate measured for uncoated rebars.

When Si and Ti powders were mixed in the bed, a thin (1<µm) Fe-Si-Ti coating was deposited. The corrosion rate was about eight times lower than for uncoated rebars.

In this project, tasks will be performed in a scaled-up reactor to deposit the Si-Ti coatings on 3-foot (0.9-m) rebars. The experiments will determine the effect of temperature and rebar composition on the rate of deposition.

The effect of deposition temperature and rebar composition on the thickness and microstructure of the coating and diffusion profile at the interface was first determined using a small, vertical fluidized bed reactor. Short 1-inch (25-mm) samples were cut from the commercial rebar and immersed in the bed of mixed Si and Ti powders and coated at 500, 600, and 700°C. SEM, EDAX, and x-ray diffraction (XRD) analyses were performed on the coated surfaces as well as on the cross sections of the samples to determine the morphology, thickness, and composition of the coatings The coatings were all compact and adherent. No changes in the microstructure of the underlying substrates, even at the highest coating temperature, were observed. The study of the crosssection of the coating obtained at 600°C shows that acid (used to define the coating-substrate interface) etched the iron rebar substrate preferentially. The

[1]The IDEA project started in April 1994 and will be completed by March 1995. The IDEA project advisor is David Manning, Ontario Ministry of Transportation, Canada.

coating by contrast was not attacked appreciably. The coating varied in depth penetration from 0.001 inches (25 μm) to over 0.002 inches (50 μm). The coating on the surface of the rebar contained about 10% Si, 8% Ti, and 3% manganese (Mn). The cut end of the rebar had 3% Si and Mn, and the rest was Fe. The coating rates were slower than previously obtained. At the highest temperature, a deposition rate of less than 1μm/minute was obtained. Data are being collected to show that the high contents of Mn in the rebars may be limiting the rate of deposition. The nominal bulk content of the CSR rebars contains 1.2% Mn, whereas those used in previous experiments contained less than 0.5% Mn. In addition, the surface of the rebar shows concentration in Mn over 3%, according to energy dispersion x-ray analysis. It is likely that the amount of Mn plays an important role on the coating process. A computerized thermochemical modeling program will be used to estimate the stability of manganese chloride ($MnCl_2$) and the rate of deposition of its presence on the surface of the rebar.

The design and construction of a scaled-up reactor for coating 3-foot-long (0.9-m) rebars has now been completed. Figure 1 is a schematic of the reactor system, which consists of a heating unit, a gas feeding unit, a reactor unit, and a scrubbing unit. The rebar is heated directly by a 25KVA, 450KHz induction coil similar to those used in current polymer coating reactor. Experiments with a four-turn, 4-inch-diameter (100-mm) coil has been performed, and demonstrations have shown that a 1-foot (25-mm) length of a rebar that is 0.5-inch (12.5-mm) in diameter and 3 feet (0.9m) long can be heated directly to temperatures up to 700°C in 1 minute. The Si powder mixture is loaded to 10 mm high in a horizontal tray. The powders are fluidized by gas injected in the bed by a tube with multiple pinholes that is immersed along the bottom of the bed. The rebar is fed

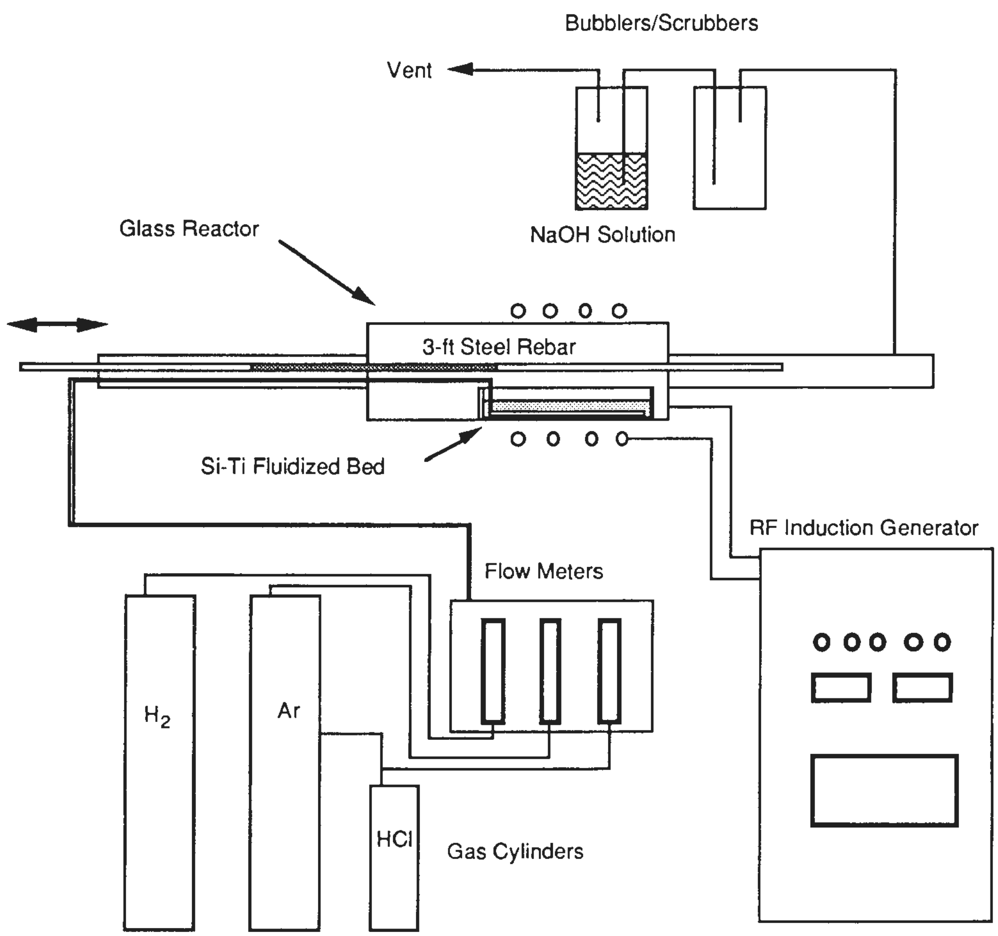


FIGURE 1 Reactor system.

and coated continuously. The coated bar is then allowed to cool down in the chamber to the right of the fluidized bed.

In the next 3 months the project will test the effect of coating properties of rate of feeding, and temperature deposition will be explored. The coated rebars will be tested for corrosion resistance after bending. Some coated rebars will be sent for further study at Western Coating and will be exposed to Pacific Gas & Electric Company plants located on marine sites.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The investigators are working closely with an industrial coater, Western Coating of Oregon. Based on user input, conditions similar to those expected to be found in industrial production will be simulated. Most of the chemistry on the Si and Ti powders will be completed before treated powders are shipped to the coating plant, where they will be coated in cooperation with Western Coating. A broad user demonstration of the method is planned.

REHABILITATION OF STEEL BRIDGES THROUGH APPLICATION OF ADVANCED COMPOSITE MATERIALS

NCHRP-IDEA Project 11[1]

Dennis R. Mertz,[2] *John W. Gillespie*[3] *and Vistasp M. Karbhari,*[3] *University of Delaware, Newark*
Kazuhiko Kasai,[2] *Lehigh University, Bethlehem, Pennsylvania*

IDEA PRODUCT

Adhesive or fusion bonding of advanced composite materials for rehabilitating steel highway bridges will be evaluated, and retrofit design guidelines using a plate bonding process will be developed.

Adhesive or fusion bonding composite plates to the flanges or webs of rolled beams or built-up riveted or welded steel plate girders would be less labor-intensive than field bolting steel plates and less damaging to the deteriorated component than field welding. Fusion bonding composite plates to steel will not produce significant fatigue-inducing flaws in the steel because of to the low heat input. Further, the composite plates are non-corrodible. Composite plates to be bonded to flanges to enhance bending resistance can have their fibers oriented for maximum effect, unlike the relatively isotropic steel cover plates. Similarly, composite plates designed to enhance shear resistance of deteriorated webs can have a different fiber orientation to resist shear.

CONCEPT AND INNOVATION

Adhesive or fusion bonding of advanced composite materials to deteriorated steel components may prove to be a better, more durable solution for rehabilitating or strengthening steel highway bridges than traditional methods. Conventionally, deteriorated steel components are rehabilitated or strengthened by field bolting or field welding a steel plate to a component's flanges or webs. The process of field welding steel plates to deteriorated components introduces such severe fatigue-inducing flaws at the ends of the plates in the base metal of the deteriorated component that most jurisdictions prohibit it. There is also concern about the ability of the deteriorated steel component to be welded and the risk of fracture with welding. The process of field bolting retrofit plates is very labor-intensive. In many cases the original source of deterioration is corrosion. The retrofitted all-steel assembly will be equally subject to corrosion.

Rehabilitating the patrimony of deteriorated steel bridges with advanced composite materials may be an intelligent solution to the problem of improving the reliability and service life of bridges. Further, the light weight of composites, compared with traditional materials, will allow faster rehabilitation and thereby decrease traffic delays due to lane or entire bridge closings during rehabilitation. The cost savings due to more limited delays and traffic rerouting, if quantified in terms of costs to society, would allow the use of even more expensive non-traditional materials for bridge rehabilitation.

IDEA PROJECT INVESTIGATION AND PROGRESS

The main objective of the IDEA investigation is to determine the feasibility of rehabilitating and strengthening existing steel bridges through the application of advanced composite materials. A secondary objective is to apply existing advanced composite materials technologies from other industries, such as the military and aerospace industries, to the civil infrastructure.

The technical issues related to the evaluation of rehabilitating and strengthening existing steel bridge members by attaching composites can be summarized with four basic questions:

[1]The IDEA project started in July 1994 and will be completed by June 1995. The IDEA project advisor is Charles Roeder, University of Washington, Seattle.
[2]Associate Professor, Department of Civil Engineering.
[3]Associate Professor, Department of Civil Engineering.

1. Can the advanced composite materials attached to existing steel bridge members enhance their static strengths?

2. Will the resultant retrofitted steel bridge member be durable?

3. Can the advanced composite materials be quickly and successfully attached in the field?

4. Can traditional maintenance forces be trained to attach advanced composites to steel bridge members?

The steps necessary to evaluate the feasibility of rehabilitating and strengthening existing steel bridge members by attaching composites and their application to highway practice consist of the following demonstrations, which answer the previous questions:

1. Attaching advanced composite materials to the flanges and webs of steel bridge members enhances their static bending and shear resistances, respectively.

2. Attaching composites strengthens steel bridge members. The durability of the strengthened member can be defined by the fatigue resistance of the strengthened member (the last of the fatigue resistances of the advanced composite material, its attachment to the steel, or the steel member itself), and the effects of the environment in terms of deterioration on the composite material and its attachment. It is proposed that this demonstration of durability follow the successful completion of the IDEA project.

3. Advanced composite materials can be quickly and successfully attached in the field to existing steel bridge members. This demonstration involves ensuring that the equipment involved in the processes of attaching the composites to the existing steel, either for the application of heat or pressure or for the preparation of the existing potentially weathered steel surface, is portable; and that the field conditions, such as temperature, access, and cleanliness, are acceptable for the processes. For the concept to be cost-effective, the attachment of the advanced composite materials must be quick so that the increased material costs will be offset by reduced labor and disruption of traffic.

4. Existing construction and maintenance forces can be easily trained to attach composites to steel bridge members and to maintain them.

This investigation will concentrate on demonstrating the feasibility of enhancing the static behavior of existing steel bridge members retrofitted through the application of advanced composite materials. Although the fatigue resistance of steel beams rehabilitated with composites and environmental effects on composites and bonding agents are significant considerations affecting the ultimate feasibility of this concept, the static behavior must first be understood in order to establish a baseline from which fatigue and environmental damage cause deviation.

The experiments are designed to determine the incremental strength achieved through adhesive or fusion bonding composite plates to steel beam specimens. In addition, the overload behavior and ultimate failure mode will be determined. Test specimens will include rolled beams with plates attached to flanges and webs. The fibers in the composites will be oriented to optimize system performance for attachment to flanges and webs. The composite plates will be attached through existing composite bonding technology. The effect of surface condition, (i.e., deterioration due to corrosion) on bonding effectiveness will be studied through a brief study of small-scale coupon-type specimens.

The work plan consists of two parts:

- *Stage 1*: A broad investigation of smaller-scale steel rolled beams strengthened through the bonding of composite plates, and
- *Stage 2*: Limited testing of large-scale steel bridge members using the configuration deemed most promising after Stage 1.

Stage 1

The experimentation program of Stage 1 is designed to demonstrate the range of feasibility of the concept of rehabilitating and strengthening steel bridge members through the application of advanced composite materials. A total of 26 steel beams of small section size, strengthened with advanced composite materials, will be tested. For reasons of economy of fabrication, it was decided to use a W8x10 rolled section of A36 steel as the small-scale test specimen. The chosen section is relatively deep compared with its width and has proportions closer to those of a typical bridge girder. To ensure the adequate replication of results, three of each type and configuration of specimens will be tested. Two strengthening configurations will be investigated: (a) cover plating the flanges to enhance bending resistance, and (b) applying doubler plates to the web to enhance shear resistance. Two types of composite plates will be included, and two methods of bonding will be employed. This results in a total of 24 test specimens (3 specimens for replication x 2 strengthening configurations x 2 composites x 2 bonding methods). In addition, two bare beams (with no composites attached), one bending specimen, and one shear specimen will be tested to provide a benchmark for assessing the performance of the strengthened beams.

To demonstrate the range in feasibility of retrofitting steel bridge members with advanced composite materials, two types of composites will be applied to steel members. These two composites will bound the range of potential composites to be applied to rehabilitate steel bridge members in practice. A graphite-epoxy composite, at the high end of the range of composite strengths, and a glass-polypropylene or glass-polyester (both in preimpregnated sheet form) composite, at the high end of the range of composite toughness, are the two systems to be used.

The two currently most promising methods of attaching the composites to metals—adhesion bonding over the entire area of the composite and fusion bonding in a sequential fashion throughout the area of the composite—will be used to bond the composites to the steel rolled beams.

Two test setups are proposed. For the bending resistance test, the specimens will be tested in simple four-point bending with a span of 4 feet (1.2 m). The span is long enough to ensure flexure yielding (i.e., tension and compression yielding primarily in the flange regions). To enhance bending resistance, cover plates of advanced composite materials will be bonded to the beams' flanges in the constant moment region between the applied load points as well as some portion of the gradient moment region. The test will quantify the effect of the composite cover plates on the elastic deflection, yield capacity, ultimate flexure capacity, local instability, and ductility of the beams.

For the shear resistance test, the specimens will have a span length of 1 to 1.5 feet (0.3 to 0.45 m) and will be tested in three-point loading. The span is short enough to ensure shear yielding (i.e., shear yielding in the web regions) rather than flexure yielding of the beam. To enhance shear resistance, doubler plates of advanced composite materials will be bonded to the beams' webs. The test will quantify the effect of composite doubler plates on the yield capacity, web buckling capacity, ultimate shear capacity, and ductility of the beams.

Stage 2

The experimentation program of Stage 2 will concentrate on two full-scale demonstrations of the most promising configurations, one for bending and one for shear, resulting from Stage 1. These full-scale specimens are considered prototypes for the advanced testing (which must include fatigue testing) that must follow for full acceptance by the bridge community.

These specimens will be more of the scale of actual bridge members. The rolled section proposed is W18x35. For the bending resistance test, two specimens of 15-foot (4.5-m) span length with and without composite cover plates will be subjected to simple four-point bending. For the shear resistance test, two specimens of 2-foot (0.6-m) span length with and without composite doubler plates will be subjected to three-point loading. The bending test requires about 120 kips (535 kN) of maximum actuator load; the shear test requires about 400 kips (1780 kN).

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The investigators are working with the Advanced Research Projects Agency's Technology Reinvestment Program investigating composite material applications for the civil infrastructure. If this IDEA innovation proves feasible, the Delaware Department of Transportation will be requested to cooperate in a demonstration of the method on a corroded steel bridge.

ADVANCED TESTING OF AN AUTOMATIC NON-DESTRUCTIVE EVALUATION SYSTEM FOR HIGHWAY PAVEMENT SURFACE CONDITION ASSESSMENT

NCHRP-IDEA Project 12[1]

Sidney Guralnick[2] *and Eric S. Suen*[2]
Illinois Institute of Technology, Chicago

IDEA PRODUCT

A new, commercially viable non-destructive evaluation (NDE) system for the real-time inspection of highway pavement surfaces using the shadow moire technique coupled with advanced computer-controlled video- and image-processing technologies is demonstrated. The project, through field testing and subsequent data analysis, will demonstrate the efficacy and cost-effectiveness of this unconventional technique for the in situ detection and recording of pavement distresses that are related to pavement performance. In particular, the significant pavement distresses to be monitored automatically are rutting and shoving (waves, sags, and bumps), washboarding and depression, potholing, patching and out-of-plane cracking or deformation.

If the system proves successful, highway officials will be able to obtain roadway surface topography and distress information much more rapidly and economically than they can with current methodologies. This approach has the potential to improve the maintenance inspection of highway systems, produce large pay-offs, and become a significant technological breakthrough.

CONCEPT AND INNOVATION

Moire interferometry, due to its high sensitivity and accuracy, has become one of the most important means of analyzing surface strain and displacement of deformable objects. In the shadow moire method, the shadow of the reference grating as cast on the object surface is used as the specimen grating, that is, the moire fringes are formed between a grating and its shadow on the surface of the object. The shadow of the grating will be distorted by the out-of-plane deformation of the surface; when viewed together with the reference grating by means of a camera, moire fringes are created that represent the topography of the pavement surface.

Conventional road analysis techniques or manual visual inspection techniques are costly and time-consuming processes that are inadequate to the task of providing meaningful quantitative information. Prior research using a reduced-scale laboratory apparatus has demonstrated that it is possible to obtain in the laboratory, with the shadow moire technique, all of the information needed to reconstruct the entire three-dimensional surface of a segment of highway pavement surface. Furthermore, it has been demonstrated that the reconstruction can be accomplished automatically with computer-aided image processing and image analysis techniques.

Currently, the most frequently used manual pavement assessment methods require personnel to work near or directly on the pavement surface. Therefore, these personnel are placed in great danger when working immediately adjacent to passing traffic, even when proper traffic signing and flagging procedures are used. The proposed investigation suggests that these surveys can be made automatically from a moving vehicle. Hence, it fills a need felt by most highway departments. Both domestic and foreign manufactured units exist that purport to accomplish some of the same purposes of the proposed system. Unfortunately, most of the existing equipment produces poor images, which require costly and time-consuming processing operations (involving human operators in some cases), and this equipment is expensive. In addition, these units are so delicate and sophisticated that they require the full-time services of several specially trained technicians. The overall advantages of the proposed system compared with other existing products are low costs, system reliability, high quality of data, high survey rate (frame sampling rate), manufacturer support, excellent system flexibility, and adequate data storage capacity.

---

[1]The IDEA project started in July 1994 and will be completed by June 1995. The IDEA project advisor is Rudy Hegmon, Federal Highway Administration.
[2]Professor, Department of Civil Engineering.

IDEA PROJECT INVESTIGATION AND PROGRESS

An automated video image analysis system developed in the laboratory consists of a high resolution electronic shutter charged coupled device (CCD) camera, a high-resolution industrial-quality videocassette recorder (VCR), a video monitor, a real-time image processor subsystem, and a host microcomputer. This system features a high degree of automation, and it has been found in the laboratory to yield satisfactory images and accurate results.

The prototype has been designed to record the image data of moire fringes on high-resolution videotape during a highway field run so that the video tape can be returned to a central facility to be processed by a computer-controlled image processing and analysis system. The previously developed reduced-scale laboratory system uses a high speed shutter-controlled camera and an image freezer, which permits a "snapshot" video picture to be made at shutter speeds up to 1/10,000 second. This approach yields excellent surface images.

The image processing subsystem selected is provided with a bus interface to a microcomputer. The base configuration includes a seven-slot chassis host computer interface, analog/digital interface, frame buffer, and pipeline processor. This high-speed image processor can perform 10 million operations per second.

Preliminary image analysis software, written in the high-level C programming language, has been developed with a variety of image acquisition and processing functions from Imaging Technology's ITEX 151 software library. The video analysis software developed consists of two major components: a feature enhancement processor and a fringe analyzer. The feature enhancement processor increases the contrast between the desired feature and the surrounding background. Therefore, this processor expands the computer's ability to detect noisy fringes in the video frame.

Several feature enhancement schemes will be implemented and field tested for the purpose of improving the contrast in the raw video data. Once the image has been enhanced to improve the contrast between the desired features and the image background, then the video data are transmitted to the fringe analyzer. The fringe analyzer must be capable of taking up the enhanced video data, counting the fringes, and cataloging the surface of interest.

The error distribution obtained using several groups of parameters with individual independent tests is shown in Figure 1. It may be observed from this figure that the errors for each group were smaller than 2.5%, with only a few

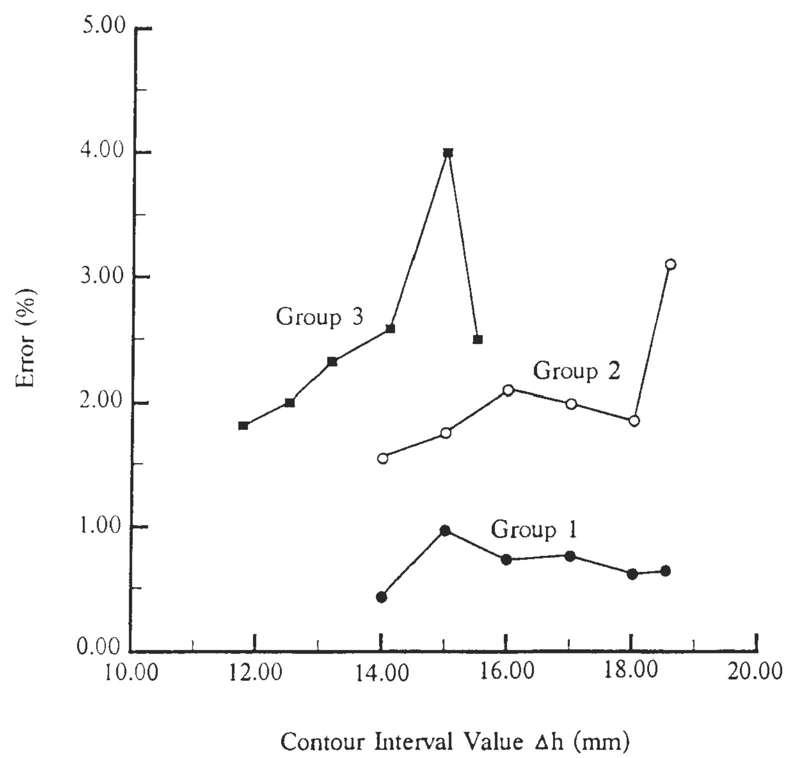


FIGURE 1 Error distribution for various groups of parameters.

exceptions. At all exceptional points, the particular arrangement of the geometry of the apparatus produced large amounts of glare. When an ordinary polarizing filter was mounted on the lens of the video camera, the glare and, consequently, the exceptional errors were reduced greatly.

A road inspection vehicle has been selected that provides adequate interior space to install all of the data acquisition equipment and that is easy to modify to accommodate all of the image analysis hardware. A large trailer has been selected for ease of installation of the system and for the convenience of the two-man crew when traveling on the road. After detailed studies of alternatives, a single-axle trailer was chosen. The vehicle selected is 7 feet wide and 10 feet long and it possesses the following advantages: low cost, adequate space, and excellent flexibility. This vehicle was modified and outfitted to house the optical and electronic equipment needed to record pavement condition in real time at a road speed of 30 to 40 miles per hour. The vehicle supports the moire grating and the light sources, and it houses electricity generators, VCRs, and VCR controllers. The trailer with the towing truck is shown in Figure 2.

Experience with large gratings uncovered a problem with sagging of the grating strands. This led the investigators to design two smaller gratings instead of one large grating, thus halving the strand length and eliminating the undesirable effect of excessive strand sag. The current design for the smaller gratings utilizes an aluminum frame and strands made from polyethylene. The dimensions of each of the new gratings is 36 x 36 inches with a pitch of 2 mm. The prototype road inspection vehicle is designed to accommodate two such gratings for wider road pavement coverage. The equipment mounting frame was designed and constructed to conform to the dimensions of the prototype road inspection vehicle.

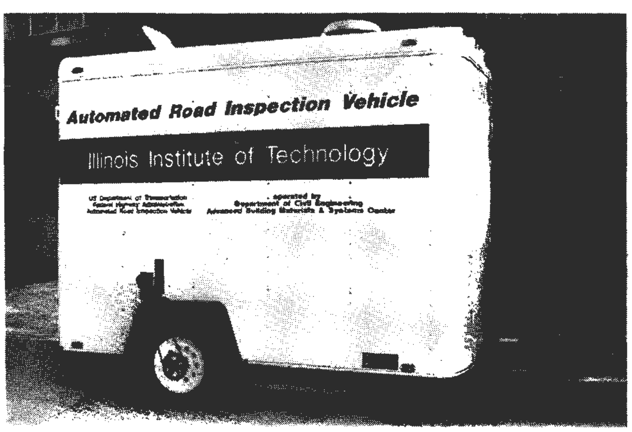


FIGURE 2 Automated road inspection vehicle during field testing.

Three directional lighting units were installed on a suitable mounting frame with a combined total output of approximately 4,500 watts. An aluminum mask with a single slit was installed underneath the lighting units with the slit parallel to the strands of the grating(s). This mask effectively polarizes the light to produce a plane wave, perpendicular to the direction of propagation of the light. Tests with an optical condenser lens placed between the lighting units and the mask are being conducted in an effort to concentrate more light through the slit. This effort is expected to produce more contrast in the shadow moire image while allowing for a wider, evenly luminescent light projection on the grating(s).

A ventilation system was designed and installed for the road inspection vehicle to protect the electronic components console from thermal damage due to heat buildup from the lighting units. This ventilation system consists of a fan unit on or near the ceiling of the vehicle; the fan extracts heat buildup from inside the vehicle. The design of this fan unit prevents ambient light from outside the vehicle from entering the inside of the vehicle, thus precluding stray unpolarized light from saturating the shadow moire image.

Since many shadow moire patterns will be acquired, a fast screening process is necessary to determine whether a particular frame needs further processing. This process ultimately distinguishes "bad frames," corresponding to badly damaged road surfaces, from frames corresponding to road surface with little or no damage. After further processing of bad frames, corresponding road surfaces can be rated to determine the extent and magnitude of the damage.

A grating parallel to the surface of interest was used and the number of shadow moire fringes along predetermined vectors in each frame was counted. Since the extent of surface damage is related to the number of fringes observed, counting fringes in each frame produced good screening results. The pixel intensities are read along each vector, and the profile of pixel intensities along the vector is computed. The maximum error possible in counting the number of fringes is ± 1 for the algorithm that has been developed. Multiple counting directions are required because of the nonlinear nature of fringes. It should be noted that a surface with no distortion or a surface whose distortions are very small yields a frame with no fringes. This was the basis of our fast screening process. Various algorithms were developed and tested to produce a screening process dependent on the quantity of fringes present in each frame. If the number of fringes in a frame exceeded a preset value in the algorithm, then that frame would be categorized as a bad frame.

A more elaborate approach is currently under investigation. This approach uses a slightly tilted grating relative to the surface of interest. A tilted grating will cause fringes to appear even if the surface is perfectly plane. The greater the angle of tilt, the larger the number of fringes that will appear. It has been demonstrated in previous research that the equation derived for the shadow moire method in which the grating is not tilted holds good as long as the tilt angle is not greater than 10 degrees. Another advantage of using a tilted grating is the ability to differentiate between concave and convex deformations in the surface of interest. The main difference between a tilted grating and a parallel grating is that a tilted grating produces a pattern of linear horizontal fringes even when there are no surface deformations or when surface deformations exist that are too small to be of interest.

To determine the location of specific areas of surface distress accurately, a distance measuring subsystem was developed that incorporates a high-speed sensor, a programmable pulse counter, an octal relay and a U-Matic VCR. A circular disk with openings that are equally spaced is used that is geared to the wheel of the prototype road inspection vehicle. By using the emitter and detector fiber optics cables of the sensor at the wheel base, a pulse for a specific distance traveled by the prototype road inspection vehicle is obtained.

Since the pulse counter is fully programmable, allowing for pulse count presets, the number of pulses needed to travel the distance equal to the length of the moire grating can be preset. Once this predetermined distance is traveled, the pulse counter activates a high-speed octal relay, which triggers the video acquisition system to snap a picture of the pavement surface moire fringe pattern. The pulse counter then automatically resets to zero and the whole procedure repeats again for each interval of travel (equal to one grating length).

The pulse counter is preset to activate a relay for every 3-foot interval that the prototype road inspection vehicle travels. The relay in turn triggers the video acquisition subsystem to capture the shadow moire fringe pattern visible on the 3-foot-long grating. The distance traveled is calibrated by changing the number of pulses preset on the pulse counter. Small changes in the tire height of the inspection vehicle due to temperature expansion and contraction can be corrected easily by means of this calibration.

The video acquisition subsystem uses a professional-grade U-Matic VCR. As the prototype road inspection vehicle travels, the VCR continuously records the video information sent to it. In the current implementation, video information relating to the fringe pattern at every 3-foot interval of travel is sent, but no video information is sent between the 3-foot intervals. This technique produces a repetitive pattern of full images separated by black images. The black images correspond to no video information being sent to the VCR. Hence, every repetition of a full image and a black image corresponds to a 3-foot travel of the inspection vehicle. By numbering each of the full image/black image repetitions using a computer, image processor, and a numbering algorithm, the number of 3-foot intervals that the vehicle has traveled can be accurately determined.

Most of the error accumulated with this system arises from two sources. The first comes from the perforated circular disk. If there are a large number of perforations, then many more pulses from the sensor occur during the 3-foot interval of travel. This provides a more accurate measurement of such an interval, and it also makes recalibration more efficient, thus reducing error. Error is increased if only a few perforations are used, making recalibration more difficult. The second source of error is related to the number of times that recalibration is carried out during the field test. Since a certain number of pulses pertains to the 3-foot interval at any given time, the interval traveled may increase or decrease, depending on tire temperature. Thus recalibration is achieved by adjusting the number of pulses that pertain to an actual 3-foot interval of travel.

The aforementioned distance-measuring subsystem is much more accurate and stable than a conventional fifth wheel. A simple fifth wheel is prone to skipping, especially on bumps and potholes. The fifth wheel cannot be corrected for thermal expansion, either, since it counts each revolution, unlike this system, which counts many times (as pulses) in each revolution.

A good probabilistic deviation prediction model plays an important role in a highway pavement management system. It may be used to predict the future condition of pavements treated with a given maintenance and rehabilitation action. It may also be used to compare the economics of various maintenance alternatives. Development of a good model for predicting the performance of a pavement has been a continuing challenge for transportation engineers. On the basis of the pavement elevation data produced by the shadow moire image processing system, it is possible to develop a suitable probabilistic deviation prediction model.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The Illinois Department of Transportation (DOT) has proposed to cooperate with extensive field trials. If field trials are successful, Illinois DOT will acquire at least one system. In addition, INFRACON, Infrastructure Management Consultants, Inc., of Arlington Heights, Illinois, has expressed a strong interest in leasing one system after field trials are successfully completed. Experience with the prototype system is expected to lead to widespread acceptance of the system by state transportation departments as well as by private transportation facilities and management consulting firms.

NEW ADDITIVE FOR IMPROVED DURABILITY OF CONCRETE AND PREVENTION OF REINFORCING CORROSION

NCHRP-IDEA Project 13[1]

Jack E. Stevens[2] *and James Mahoney,*[3] *University of Connecticut, Storrs*
James R. Humphrey, Todd Chemical, Cheshire, Connecticut

IDEA PRODUCT

The use of a salt of dicarboxylic acid as a concrete additive to prevent entry of water into the pores in concrete and thus prevent deterioration will be investigated.

CONCEPT AND INNOVATION

Repeated expansion forces of water freezing in concrete pores gradually destroy concrete. Air entrainment has been the preventive measure used for the past 50 years or so to prevent freeze/thaw damage. Air-entrained concrete must be placed carefully if the minute air bubbles are to be distributed uniformly. Vibration, often used to work the mix into place, can cause the buoyant bubbles to rise to the surface, leaving portions of the concrete unprotected.

If concrete has any permeability, water carrying deicing salts can reach the reinforcing bars. The ensuing rusting increases the volume and can cause the concrete cover to spall off. The use of a salt of dicarboxylic acid as a concrete additive may prevent entry of water into pores in concrete and thus prevent both forms of deterioration.

IDEA PROJECT INVESTIGATION AND PROGRESS

The IDEA project investigation will be conducted in two stages. In Stage 1, freeze/thaw, compression, and indirect tension tests will be conducted to measure the effect on physical properties. In Stage 2, the dosage for maximum benefit will be determined. Porosity and capillarity tests will then be conducted as indicators of the degree to which rusting of the steel can be reduced.

The wide acceptance of fly ash as a mix additive raises the question of metals leaching from concrete. Total chemical leaching potential (TCLP) tests will be carried out on fly ash mixes with and without the proposed chemical additive to determine if the reduced porosity and locking metal ions by the dicarboxylic acid salt also reduce leachates. If so, incinerator fly ash could be used in concrete.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

If successful, this IDEA product could be used by concrete users requiring improved concrete performance; because the dicarboxylic salt solution would be dispersed in the mixing water, the treatment would be insensitive to placement of techniques.

[1]The IDEA project started in September 1994 and will be completed by June 1995. The IDEA project advisor is V. Ramakrishnan, South Dakota School of Mines, Rapid City.
[2]Professor, Department of Civil Engineering.
[3]Research Assistant, Department of Civil Engineering.

UNREINFORCED, CENTRALLY PRESTRESSED CONCRETE COLUMNS AND PILES

NCHRP-IDEA Project 14[1]

D. V. Reddy,[2] Florida Atlantic University, Boca Raton
Paul F. Csagoly, Consultant, Clearwater, Florida

IDEA PRODUCT

The concept of unreinforced, centrally prestressed concrete piles and piers is developed and tested, and the feasibility of the method for application to highway structural systems is demonstrated. Comparative tests indicate higher compressive strength on unreinforced concrete column stubs than on reinforced ones. Computations forecast that unreinforced, centrally prestressed piles and bridge piers have adequate axial and flexural resistance as well as ductility. Because of large cover and absence of shrinkage cracks, its resistance to corrosion is substantially improved with the associated retention of long-term structural integrity. Unreinforced, centrally prestressed piles and piers are expected to reduce initial cost, accelerate construction, and improve corrosion resistance.

CONCEPT AND INNOVATION

The unreinforced, centrally prestressed concrete column or pile is an innovative structural concept that permits the treatment of a compressive member as if it were a flexural member. The prestressing strands are bundled into a centrally located cable that is anchored into the substructure at the bottom and into the superstructure at the top. After prestressing, the cable is grouted to provide for composite action by bond. Neither longitudinal nor transverse steel is present.

Concrete columns with high steel ratios exhibit regularly spaced annular shrinkage cracking. The cracks may destress the concrete and make the steel unable to carry the axial load. In other words, in such a case, the longitudinal steel does not prevent but causes shrinkage cracks. In the cold regions, concrete bridge columns are exposed to splashing, spraying, or percolating salt-laden water. Shrinkage cracking may accelerate the entry of chlorides into the concrete, resulting in the corrosion of steel and spalling of the cover.

The unreinforced, centrally prestressed concrete compressive member is believed to have no structural incompatibility between concrete and steel. The concrete is in compression and the steel is always in tension, as they should be. Designing for either a calculated or specified eccentricity is an administrative rather than a technical decision. It should be remembered, however, that perfectly central loading is not possible in reality, and that superposition of axial and flexural stresses in the inelastic mode is structurally incorrect, notwithstanding various interaction formulas permitted by current codes. In no particular order of importance, the following advantages of the proposed column design in bridge construction can be listed:

- Economy due to substantial reduction in steel, even if the high-strength steel is slightly more expensive;
- Improved corrosion protection by duct and considerable increase in cover;
- Elimination of shrinkage cracks;
- Ease of design, as the strands can be represented by a single bar in both elastic and inelastic analysis;
- Ease of construction, as the absence of steel gauge allows good compaction of concrete, and thus the successful application of high-strength concrete;
- Elimination of the need for splicing of reinforcing steel in tall columns; and
- Ease of splicing of precast and prestressed piles.

In earthquakes, where force effects are generated by the mass of the bridge in response to ground acceleration, such responses can be mitigated by placing energy-absorbing devices in strategic locations on the bridge. One such device, which is compatible with central prestressing, is the modified Freyssinet hinge, illustrated in Figure 1. In this innovative design, the hinge concrete (or potentially some high-strength

---

[1]The IDEA project started in September 1994 and will be completed by September 1995. The IDEA project advisor is Anthony Garcia, DRC Consultants, Tallahassee, Florida.
[2]Professor, Department of Ocean Engineering.

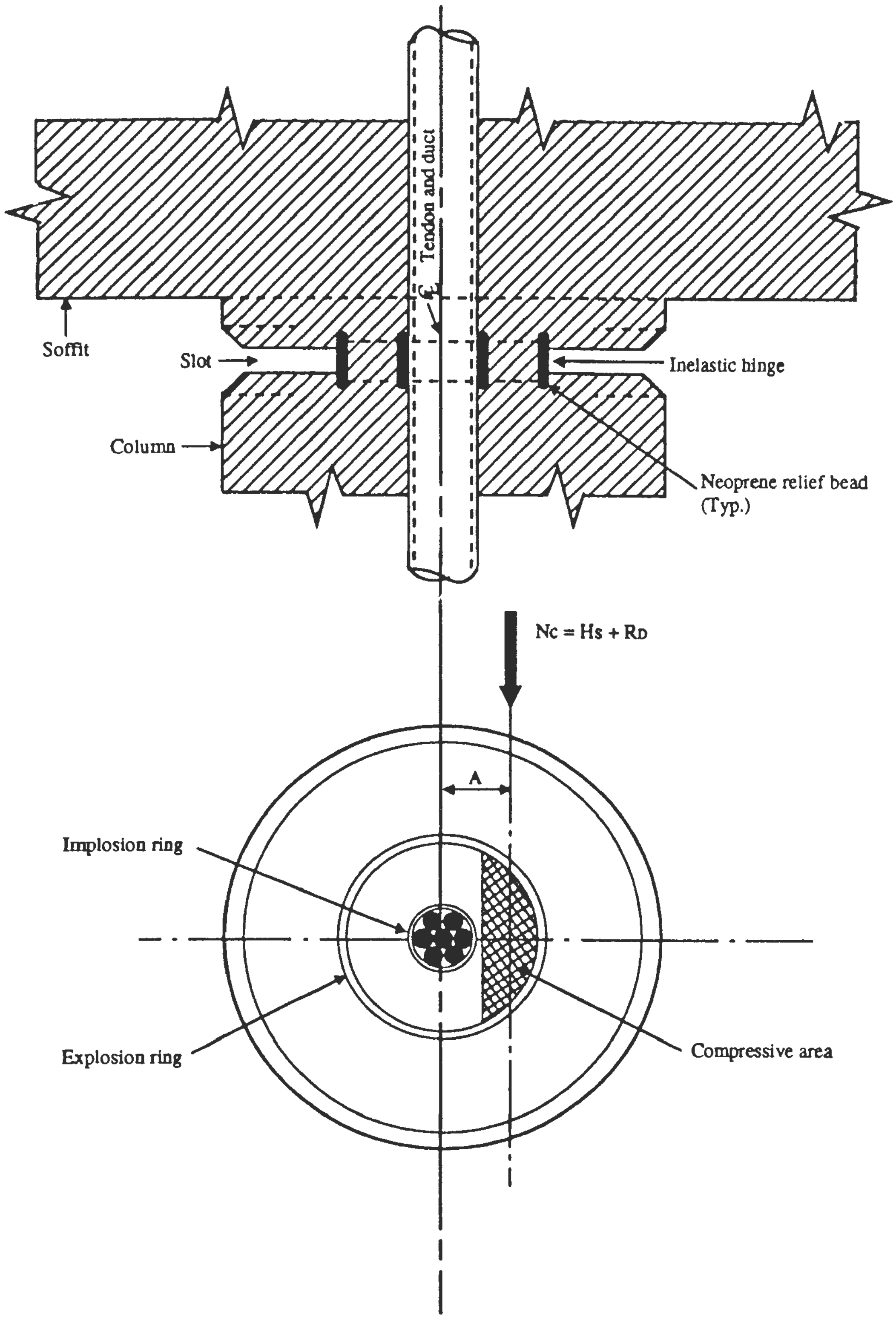


FIGURE 1 Freyssinet hinge modified for earthquake.

granular material) is laterally confined by inside and outside steel rings, the former permitting passage of the prestressing cable. The steel rings are deactivated from carrying vertical load by neoprene rings fastened to them. To resist splitting forces, the column is fitted out with a metal band at a short distance from the hinge.

The hinge material, being under triaxial pressure, is believed to possess substantial plastic capability by which

- Energy can be absorbed without structural distress,
- Force effect is mitigated in general, and
- Moments (and thus shears) transmitted to the column are limited to a predetermined value.

The rings can be manufactured from standard heavy-duty pipes. Therefore, the cost of the hinge is infinitesimal. The hinge does not work without prestress, an important consideration when vertical ground acceleration is also present.

IDEA PROJECT INVESTIGATION AND PROGRESS

Concrete column stub tests carried out prior to, and independently of, this project indicated that

- Compressive strength of unreinforced stubs was 95.7% that of the standard 6 x12-inch control cylinders.
- The fracture mechanism was lamellar, with the fracture surfaces being at an angle between 20° and 25° to the longitudinal axis of the stub.
- The texture of the fracture surfaces was identical with those failing in direct tension.
- Stubs reinforced with 1.22% and 2.19% uncoated steel failed at 78.3% and 87.7%, respectively, of the control cylinder strength.

Based on homogeneous material properties, tension cannot analytically be detected in prisms under uniaxial compression. A new theory, so far unconfirmed, based on a triangular disposition of the aggregates filled out and stabilized by the cement matrix, however, yields tensile stresses. Principal tensile stresses are normal to surfaces that are at 22.5° (P/8) to the longitudinal axis. Three columns damaged in the 1994 Northridge Earthquake showed this type of cracking.

The principal tensile stresses are nearly normal to both the longitudinal and transverse (ties or spirals) steel in reinforced concrete columns. Thus, the interface between the steel and the concrete cover, especially with coated steel, is a plane of weakness. In column tests, four phases of failure can be distinguished:

- Shedding of the cover,
- Debonding or dislocation of transverse steel,
- Buckling of longitudinal steel, and
- Crushing of the core concrete.

Failure of this kind had been demonstrated by at least three bridge piers in the Northridge Earthquake. Structural design codes assign extremely severe (low) resistance factors to reinforced columns, reflecting

- The structural incompatibility of steel and concrete in a compressive environment as indicated earlier, and
- The inevitable eccentricity of the axial load, which is difficult to control and for which compressive members are sensitive.

The IDEA project will be performed in two stages. In Stage 1, specific application of the IDEA concept for concrete structures will be identified. Specimens of unreinforced, centrally prestressed concrete members (columns and piles) will be fabricated. Parameters that are appropriate for assessing the suitability of the concept for broad application to concrete structures including, but not limited to, structural members designed to improve earthquake resistance will be tested.

In Stage 2, tests will be performed, and cost-effective application of unreinforced, centrally prestessed concrete to a broad range of concrete structural members including Freyssinet hinges will be demonstrated. Recommendations or design methodologies for using the IDEA technology in highway structures will be provided.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The findings, if successful, will lead to cost-effective and improved corrosion and seismic resistant bridge columns. The investigators are working with the Florida Department of Transportation and the California Department of Transportation. This will be followed by reports of the findings to the committees of the American Concrete Institute International, the Prestressed Concrete Institute, and the American Society of Civil Engineers. The effort will eventually lead to the formulation of guidelines and the development of code specifications.

A ROAD CREW PORTABLE LASER WARNING SYSTEM CONCEPT DEVELOPMENT AND DEMONSTRATION

NCHRP-IDEA Project 15[1]

Keith. F. Higginbotham
Loral, Manassas, Virginia

IDEA PRODUCT

The Road Crew Portable Laser Warning System is developed and demonstrated. The system will employ laser technology as the basis for a state-of-the-art device to improve safety for highway workers. The system will use an eye-safe laser technology previously developed for military applications and is known as the Multiple Integrated Laser Engagement System (MILES). The Road Crew Portable Laser Warning System will use a laser (0.9 micron wavelength) and radio frequency (RF) components in a portable, low-cost, reliable, and user-friendly system to significantly improve highway worker safety.

CONCEPT AND INNOVATION

The baseline road crew warning system (see Figure 1) consists of a tripod-mounted, battery-powered laser transmitter, laser receiver (detector), and audible incident warning device. The laser beam from the transmitter is reflected back to the receiver and would act as an electro-optical barrier along the highway shoulder. When the laser beam is interrupted by an errant vehicle, the detector generates an electrical signal that activates the incident alarm which warns the road-side crew to take evasive action. As envisioned, the system would be very small, all-weather, portable, battery-operated, low-cost, and highly reliable.

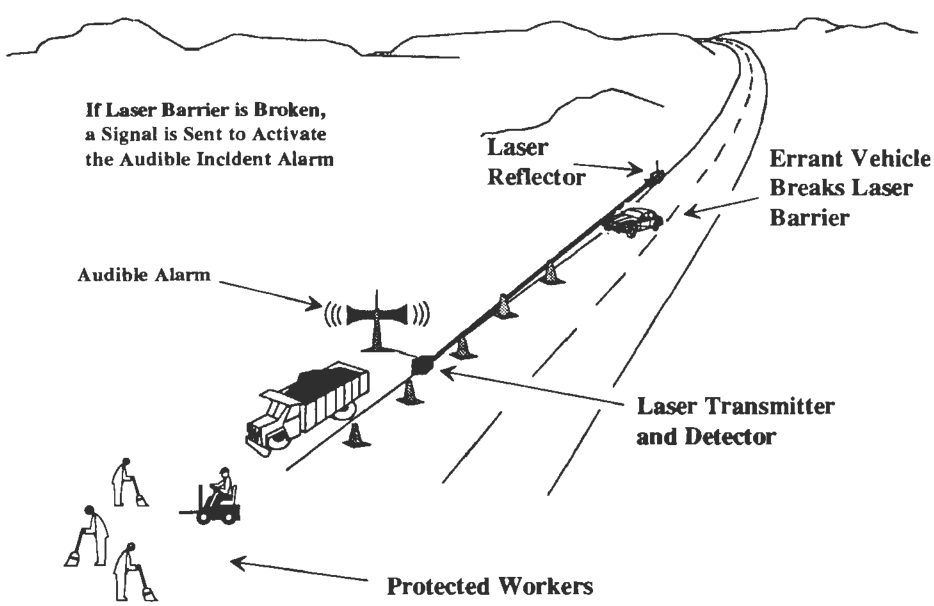


FIGURE 1 Baseline road crew laser warning system.

[1]The IDEA project started in September 1994 and will be completed by March 1995. The IDEA project advisor is Arun Shirole, New York Department of Transportation.

Alternative configurations will be investigated to compare their effectiveness with the baseline system performance. The alternative configurations will add laser and RF broadcast systems to warn the crews. In addition, a warning system designed to alert car or truck drivers that are threatening the road crew will be developed and tested.

The safety of maintenance and construction workers from traffic hazards is a major issue with both state and federal government. Road crews are subjected to significant danger posed by errant vehicles, especially in urban and rural areas. Technology inventions are needed to provide sufficient warning time for these workers to take evasive actions. The benefits, if the system is proven practical, are enormous. Of primary importance are the increased safety of roadway workers engaged in construction and maintenance activities and the reduction of death and injuries caused by traffic accidents. Additional benefits include reductions in job time lost as a result of injuries, medical costs, and insurance premiums, and increases in productivity due to an increased feeling of protection.

IDEA PROJECT INVESTIGATION AND PROGRESS

The planned tasks for this IDEA project consist of defining the candidate protection system configurations, acquiring and assembling the equipment, testing the equipment in the laboratory, demonstrating the candidate configurations, and making recommendations.

Application of MILES to Road Crew Protection

The warning system is to be based on the MILES technology developed for military applications. The MILES laser transmitter is a rugged, small, lightweight transmitter. Miniaturized optics and electronics provide the laser with the following features:

- Low power consumption,
- All commercial 9v batteries accepted,
- Low-battery indicator,
- Built-in functional test indicator,
- Qualified to stringent MIL-STD 810D environmental requirements,
- Eye-safe GaAs (904-mm wavelength) laser beam,
- Completely interoperable with all other MILES training devices, and
- Range capability of up to 2 km.

The main components of the technology are shown in Figures 2 and 3. The figures include the vest and headband with their laser detectors, the laser transmitter, and several pieces of display equipment.

For the purposes of the Road Crew Portable Laser Warning System, the vest and headband, the laser transmitter, and an RF transmitter (operating in the 300 MHz frequency range) and receiver will be used. These items are readily available from inventory.

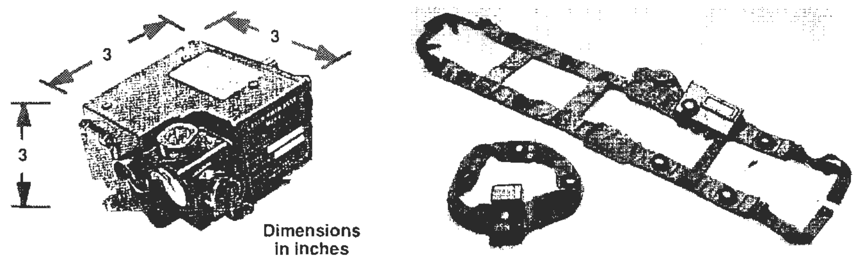
In addition to the proposed baseline system, three additional system concepts have been benchmark experiment. Two of the candidates address one of the major technical issues identified during preliminary analysis of the proposed system: false alarms caused by unintentional disruption of the laser barrier by workers. Using the laser warning system to warn drivers of vehicles that break the laser barrier and thus threaten the road crews will also be examined.

The utility of the three system concepts through analytical verification and benchmark experimentation will be evaluated. It is expected that the results of this validation will demonstrate the feasibility and desirability of the concept and lead to subsequent prototyping for operational field testing. This experiment will also look at critical design issues.

Design Issues

The primary technical issues related to the evaluation of the Road Crew Portable Laser Warning System for highway worker safety are

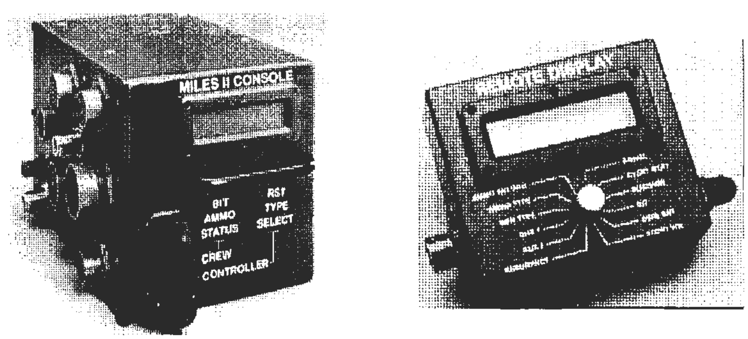
- *Effectiveness*: Can the system provide a measurable increase in the amount of warning time for potential danger to road crew personnel?
- *Reliability*: For how long is the system capable of operating without failure? For how long can the 9v battery power supply operate before having to be recharged or replaced?
- *False alarm rate*: Is the false alarm rate sufficiently low so as to prevent user personnel from being conditioned and thus ignoring the system's intended function?
- *Portability*: Can the system be set up and operated in a reasonable amount of time by untrained personnel? Can the system be relocated within acceptable user time limits?
- *Operational range*: Is the laser power and detector sensitivity sufficient to operate effectively at ranges to 400 yards?



Laser

Headband and Vest with Laser Detectors

FIGURE 2 Laser (*left*) and headband and vest detectors (*right*).



MILES Console

MILES Display

FIGURE 3 MILES console (*left*) and display (*right*).

- *Environment*: Will the system function at the maximum intended operating range of 400 yards under various highway environmental conditions? Is the system capable of operating effectively on a variety of road conditions, such as curves?
- *Visibility*: Will the system function in dusty conditions?
- *Maintainability*: Can user personnel maintain the system easily (e.g., replace 9v battery, swap out laser transmitter)?
- *Affordability*: Are the three system concepts, if produced, within the cost budget of an individual state's department of transportation?

Work to be accomplished includes defining the candidate systems, developing a test plan, acquiring the systems for test, testing, analyzing the test results, and demonstrating the promising alternatives. The work plan will include the following:

1. Investigating critical issues for the IDEA device:

   a) The contribution of the current road crew warning system to the protection of the road crew will be determined.

   b) Improving road crew warning system effectiveness supplemented by the alternatives to be tested in this project.

c) Engineering judgments will be made as to the expected effectiveness of each of the alternatives for effective road crew warning system. This process will serve as a filter to delete alternatives that do not appear to exceed the expected utility of other alternatives.

d) The test plan will address the performance of the laser warning system with current road crew protection measures (pylons, warning signs, truck barriers, etc.).

2. Developing and testing review candidate systems after the candidate warning systems have been defined:

a) The lasers, detectors, reflectors, and other equipment will be supplied by in preparation for testing each candidate system.

b) Testing will b e conducted for each of the candidates. The components will be tested in the laboratory to ensure correct operation and technical testing in a parking lot. Testing will be conducted in accordance with the test plan.

c) The test results will be analyzed to determine how well the alternatives achieve the objectives of the warning system. The analysis will include false alarm rates, ease of setup and take-down, clarity of the warning signal provided, and convenience of system operation.

3. Field demonstration of candidate systems: A field demonstration will be undertaken to show, through operation in actual highway conditions, the abilities of the various candidates to provide road crew warning. Each of the study candidates will be set up for review. Cars will be included in the demonstration to show how warning signals are generated. The demonstration will assess firsthand the effectiveness of laser-based systems.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The investigator is planning to work with the Department of Transportation in Virginia, Maryland, or the District of Columbia to perform a field test under actual highway conditions and using highway maintenance workers. The test will provide an opportunity to obtain data on the effectiveness of the road crew warning system under operational conditions. Positive test results will support the conclusion that the Road Crew Portable Laser Warning System is practical and that great safety benefits can be obtained if actual systems are put in the field. A successful concept test should also generate support within the highway community to take the next step for the development of commercial warning system that can be used by state highway agencies.

LASER REMOVAL OF PAINT ON PAVEMENT

NCHRP-IDEA Project 16[1]

Hans Pew and James Thorne
MOXTEX, Incorporated, Orem, Utah

IDEA PRODUCT

A prototype portable laser for removal of paint from the pavement of highway parking lots and air field runways will be developed. Its impact will be (a) the elimination of the usual environmental contaminants such as grit, dust, smoke, and chemicals;, (b) prevention of damage to pavement during paint removal; and (c) completion of removal for compliance with federal codes that require no visible trace of temporary markings on newly constructed roadways and disposal.

CONCEPT AND INNOVATION

Lasers typically remove paint by heating, charring, and slow burning with air or an oxygen jet. In contrast, by using a pulsed (or a fast moving continuous wave) laser, with near-infrared emission, the investigators have been able to place energy at the paint/substrate interface as well as throughout the paint. The subsequent rapid heating causes several components of paint and asphalt to vaporize and blow the paint off as small chips. There appears to be very little melting or burning—only dry chips are emitted. In contrast, slow heating generates gases slowly enough for them to escape by diffusion without damaging paint.

The approach is unique because it directs attention to the paint/substrate interface where effective removal should occur rather than to the paint/air interface, where only burning can occur. However, near the interface of interest, there must be materials that can be rapidly volatilized by energy placed in that region. Experiments show this to be true of roadway paint, even though it has been on busy roads and exposed to the elements for several years.

IDEA PROJECT INVESTIGATION AND PROGRESS

In the laboratory, the focused beam of an 80-watt neodymium/yttrium aluminum garnet (Nd/YAG) laser over samples of paint on asphalt and on concrete have been scanned. Several parameters must be adjusted to produce clean removal and to avoid road damage. Figure 1 shows a series of patches where paint has been removed to various extents that depend on the laser settings. The following are key factors:

1. Rate of heating. Slow heating allows the gas to escape by diffusion rather than by explosive removal of the paint film.
2. Penetration of laser light and its absorption near the interface. Surface reflection or absorption near the air-interface will not affect the paint/substrate interface immediately.
3. Energy density threshold (joules/square centimeter) for paint removal. If large energy densities are required, the process will not be economically viable.

Preliminary laboratory experiments have provided estimates of these key factors. For an 80-watt Nd/YAG laser focused to a 15-micrometer spot, 90-nanosecond pulses provide fast-enough heating. The 1.06-micrometer wavelength penetrates to the interface even through several coats of paint (2.5 millimeters). Only one pass of the laser is required to completely remove paint. The energy density threshold appears to be less than 70 joules/square centimeter (about half that required for published laser paint removal processes). When the laser settings are adjusted properly, the paint is removed by brittle fracture rather than by melting or burning. Microscopic inspection shows that no charring has occurred. Figure 2 shows the features of brittle fracture

[1]The IDEA project started in September 1994 and will be completed by September 1995. The IDEA project advisor is Denis Donnelly, Consultant, Denver, Colorado.

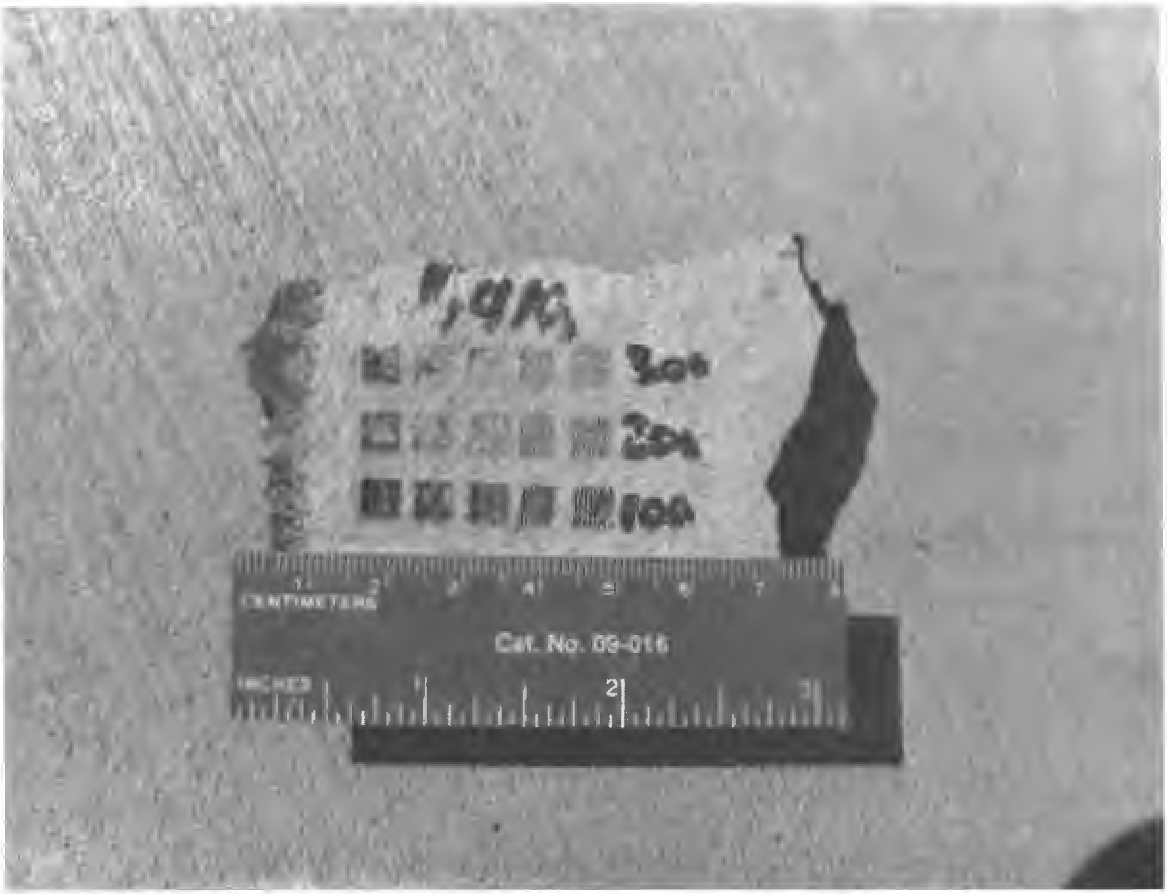


FIGURE 1 Photo showing complete and partial removal of pain from asphalt by 80-watt, Nd/YAG laser at various scan and pulse parameters.

(as opposed to melting) as revealed by scanning electron microscopy.

To develop a prototype mobile laser for paint removal, more accurate measurements of the limits of the key factors will be obtained. The 80-watt laser used in the laboratory removes an area of paint five times slower than typical sandblasting. This implies that to be competitive, a laser with at least a 400-watt output must be used. However, because of light scattering in the paint, it is believed that a larger laser spot will be more effective when measured by the energy density delivered to the surface. The energy density threshold for a larger spot will be measured from a more powerful laser to see if the threshold energy density is reduced.

Speed of heating is another important factor. It would cost less per watt if a continuous wave laser were used, and this may be possible if the focused spot moves rapidly enough for quick heating and limited loss of volatiles by diffusion.

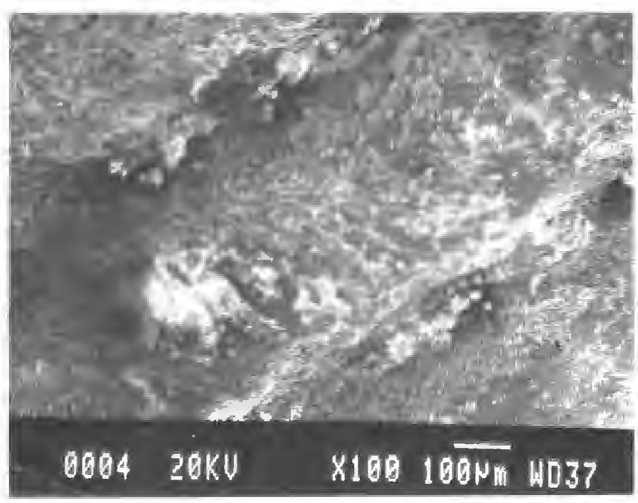


FIGURE 2 Scanning electron micrograph of a channel cut in paint by laser.

Optimizing these factors depends on the understanding of the mechanism by which energy is deposited in the paint film near the interface with the road and on the rate of generation (and leakage) of the gases generated. Spectrophotometric and chemical kinetics studies will be conducted to reveal the nature of these mechanisms. In addition, the volatile emissions from the process will be characterized to guide the engineering necessary to keep the process non-polluting.

Although both oil- and water-base paints have been successfully removed from asphalt and concrete in the laboratory, the process on other brands and other varieties of paint to explore the limits of the method will be tested. Neither the focusing nor the scattering effects of glass reflector beads (commercial or mil-spec) degrade the performance of the removal process.

Preliminary tests indicate that a jet of compressed gas is beneficial in lifting chips from the surface, and the jet may decrease the threshold energy density (and therefore the cost of operation). The jet will at least help move the chips out of the laser beam and into a fabric bag for collection.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

Using the information generated during the project investigation, a prototype mobile laser for removing paint on pavement will be designed and built. The system will be equipped with safety features and collection of the chips for disposal. If noxious gases are emitted by the process, filters to remove the gases will be installed. This prototype system will be demonstrated to highway engineers (first to the Nevada State Department of Transportation) to obtain the necessary user feedback for the next generation of a commercial version for application to highway pavements and structures.

DEVELOPMENT OF A SELF-CONTAINED PORTABLE DEVICE FOR SHRP BINDER TESTING: FIELD QC/QA TESTING WITH THE DUOMORPH

NCHRP-IDEA Project 17[1]

Samuel H. Carpenter[2]
University of Illinois, Urbana-Champaign

IDEA PRODUCT

The Strategic Highway Research Program (SHRP) developed a set of performance-based specifications for selecting asphalt binders on the basis of a rheological framework. This development represents the first time that fundamental testing will be included as an integral part of the specification and purchase process for asphalt binders. The principal test equipment for this new testing is the dynamic shear rheometer (DSR), which furnishes the dynamic properties of the asphalt binder, complex modulus, and phase angles. Low-temperature testing is provided by creep relaxation testing in the bending beam rheometer (BBR).

The IDEA product envisioned in this project is an assemblage of equipment that will provide the capability of the SHRP DSR and BBR in one package. This package will be portable and provide an increased level of durability that will allow the equipment to be stationed in hostile environments such as testing trailers at asphalt production facilities.

CONCEPT AND INNOVATION

The philosophy in current research is directed toward using surrogate tests that indicate SHRP properties by inference, or at best, regression analysis. Rather than developing surrogate tests, it is desirable to use a test that measures exactly the same properties (complex modulus and phase angle) under precisely the same testing conditions (stress, strain, strain rate), with no intermediate testing and/or statistical relationships. The duomorph has this potential. It is implantable and can function as a long-term monitor that does not require disturbing the sample to prepare it for testing. It can be implanted in several materials besides asphalt cement (e.g., synthetic resilient modulus samples, cement paste, or even bulk portland cement concrete), providing the capability of long-term monitoring of internal structural changes.

The duomorph increases the capability to obtain the SHRP structural properties in different test configurations. It is portable and can be used in the field. Because it does not contain any mechanical systems to fail, it provides potential for high durability. Miniaturization in electronics and data recording devices that are achieved each year will further enhance the portability of this device over time. The duomorph removes particle size restrictions in binder composition and opens the field of SHRP rheological testing to all binder materials regardless of composition, particularly crumb rubber binders.

IDEA PROJECT INVESTIGATION AND PROGRESS

This project will demonstrate the suitability of the duomorph technology and its applicability to the testing of asphalt binders in a manner that accurately reproduces the entire required SHRP testing program. This objective can be accomplished through a "redevelopment" of the duomorph technology with suitable adjustments, refinements, and advancements to direct the existing technology specifically toward asphalt binder testing. This fine tuning will involve evaluating new piezoelectric (PZT) material properties, sizing the sensors, using improved digital technology and newer electronic equipment, and eventually performing three-dimensional viscoelastic dynamic finite element modeling of the sensor assembly to validate the current solution schemes and extend their applicability, resulting in a field-ready device that is self-contained and portable.

---

[1]The IDEA project started in September 1994 and will be completed by July 1995. The IDEA project advisor is D. Y. Lee, Iowa State University, Ames.

[2]Professor, Department of Civil Engineering.

Equipment Assembly

The necessary electronics and piezoelectric crystals will be obtained to assemble and activate a duomorph assembly. Newer PZT materials and digital electronics have increased the potential for this device to function as a sensor in a viscoelastic material with properties similar to asphalt cement. The existing theory will be used to select sizes for the duomorph sensors that are thought to be best suited to the dynamic asphalt binder properties. This equipment will take advantage of the newer digital computer equipment for test control and data acquisition and reduction to reduce the time normally spent in hand analysis of the data. Several sensors will be assembled to provide a preliminary indication of the operational characteristics of the different sizes of sensors.

Figure 1 depicts the schematic operation of a duomorph sensor. It consists of two piezoelectric discs, bonded to a stainless steel separator. The discs are strain-gauged. The sinusoidal input voltage input activates the PZT, deforming the disc assembly into a parabolic shape. The strain gauges record the deformation of the discs, and the input and output signals are compared to show the phase angle. Comparison of the strain in air to the strain in the asphalt cement binder can be analyzed to provide the dynamic modulus of the surrounding medium. A square wave signal can provide a creep relaxation test using the duomorph assembly at lower temperatures required in the new SHRP specification.

SHRP Specification

SHRP was given the task of producing a specification for asphalt binders that was performance-related and could specify a binder with resistance to rutting, fatigue, and thermal cracking based on relationships of the measured property with the theoretical development of these distresses. This in itself is the most innovative step in asphalt testing in a long time. The SHRP specification establishes temperature ranges where a binder can be expected to perform well; the ranges extend from 80°C to -30°C. The categorization of the binders into these ranges is done entirely with rheological testing.

The first rheological test is performed on the original binder and must have a shear value of 1.0 kPa as a minimum at the specified temperature. After the rolling thin film oven test, another DSR test is performed and the shear value must be a minimum of 2.2 kPa, at the same temperature. The next step is to age the binder in the pressure aging vessel (PAV) and conduct another DSR test on this aged binder with a maximum value of 5,000 kPa at an intermediate temperature. The temperature at which this stiffness is achieved is used to set the low temperature at which the static relaxation test, the BBR test, is performed. This low temperature stiffness must be below a maximum stiffness. If the bending beam values are not satisfied, the direct tension test must be conducted. Note that it is the DSR test at the intermediate temperature that establishes the low

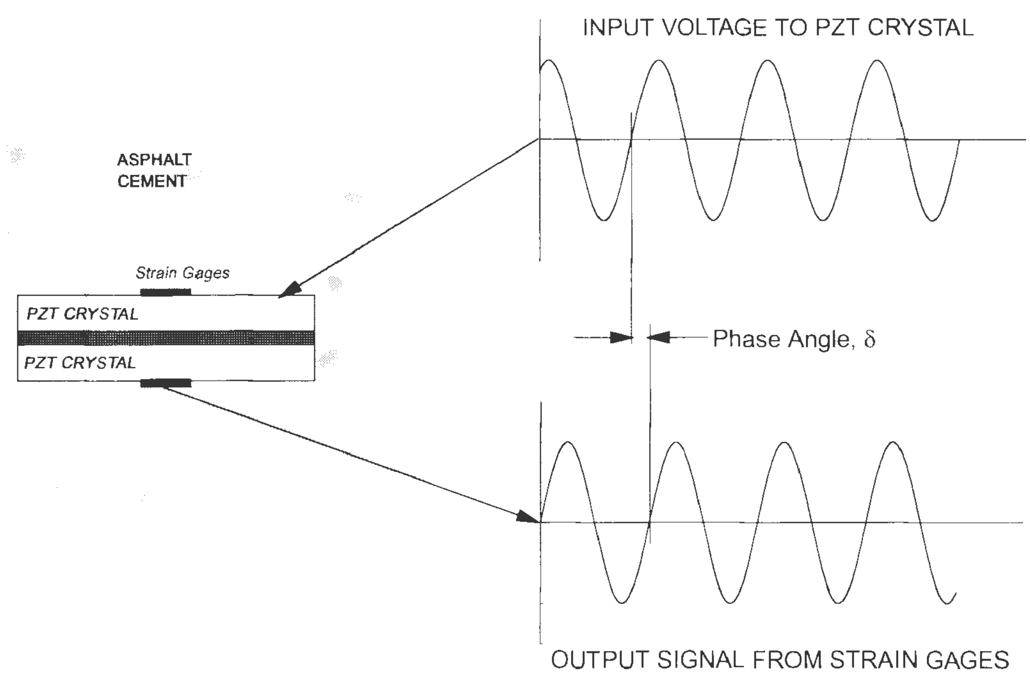


FIGURE 1 Schematic of duomorph operation, illustrating phase angle determination.

temperature grade of the asphalt cement and dictates the temperature at which the bending beam and direct tension tests must be conducted.

Duomorph Comparisons with SHRP DSR and BBR

It is necessary to test the duomorph sensors constructed to ascertain whether they can provide comparable results to the standard SHRP DSR and BBR testing. Theduomorph provides a means of varying the frequency from static to dynamic values in excess of 10,000 Hz. This capability allows the entire spectrum of SHRP testing to be conducted from the dynamic rate of 1.59 Hz (10 rad/sec) specified in the SHRP test protocol, to static (BBR) under a constant force for a relaxation test. The duomorph geometry is sufficiently different from the SHRP DSR that similitude between the devices must be established in the general sense before a detailed analytical study is conducted to fix the operational characteristics required in a duomorph gauge for SHRP specification-level testing.

A series of asphalts will be processed by the SHRP procedure and tested in the SHRP standard equipment for characterization of dynamic and static relaxation properties at the various temperatures required in the SHRP binder specification. These same asphalts will be tested with the various duomorph sensors in dynamic and static modes to develop duomorph properties. This testing will establish the potential for the duomorph to provide SHRP properties for a binder. This testing will establish if the operational characteristics of the duomorph need to be significantly different from the SHRP requirements of strain rate and strain level to obtain similitude with the SHRP properties.

Product

The product of this investigation will be the assembly of equipment that demonstrates the level of capabilities attainable with a duomorph assembly to provide SHRP asphalt binder properties over the range of temperatures required. Given the quality of data collected, recommendations may be made for assembly of a prototype device that is self-contained, has user-friendly operation software, and is as rugged and small as possible for easy, accurate field use by state department of transportation (DOT) laboratories.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

Data from the new SHRP DSR as well as from the proposed duomorph sensor will be assembled and analyzed in this project. The duomorph system device assembled here will be not an optimized device for asphalt testing but a prototype to demonstrate that this technology can be used for asphalt binder testing and to provide this equipment to local and state testing laboratories to use in a side-by-side comparison with their SHRP equipment. Implementation of acceptable technology would involve production of a field-optimized set of electronics with suitable software control that would provide data collection in as transparent a manner as is done with the SHRP equipment. This would include detailed plans and specifications for the selection and assembly of the electronics as well as for the purchase and assembly of the duomorph sensors themselves.

The fully automated device would be taken to state DOT laboratories in Illinois, Indiana, Missouri, and Wisconsin and to field construction sites to demonstrate the field capabilities for monitoring asphalt cement deliveries and to allow states to compare data with test results from their routine testing.

DEVELOPMENT OF NEW PRINCIPLES OF DESIGN OF TOOLS FOR REPAIR AND REMOVAL OF PAVEMENTS BASED ON THE EFFECT OF LATERAL PROPAGATION OF CRACKS UNDER CONTACT LOADING

NCHRP-IDEA Project 18[1]

Igor Sveshnikov,[2] *Valentin Galetsky,*[3] *and Leon Mishnaevsky*[4]
POTOK Centre, Kiev, Ukraine

IDEA PRODUCT

An innovative cutter tool design will be developed that will take advantage of a tensile propagation process of existing cracks and produce more efficient cutting and removal of concrete pavement than do conventional cutting tools used for pavement repair.

CONCEPT AND INNOVATION

The concept is based on drilling technology research and crack propagation phenomenon in hard and brittle materials under contact loading or indentation. Use of indentors with unconventional asymmetric shapes results in extensive lateral cracking in the hard rock, which facilitates the breaking and removal of the material with less consumption of energy. This procedure has led to the design of a cutting tool with improved efficiency and productivity. It is proposed that this concept be applied to highway rehabilitation technology for removing concrete pavement. If indentors are designed with innovative shapes, the resulting lateral cracks can be used to break concrete pavements in a more labor-efficient, less energy-intensive manner than conventional tools.

IDEA PROJECT INVESTIGATION AND PROGRESS

The research will involve detailed analytical and experimental work consisting of the following tasks:

1. Development and refinement of a model for lateral crack propagation in hard brittle materials;
2. Experimental verification of the model as applied to pavement materials;
3. Design of tools with innovative shapes for breaking hard pavement and development of a prototype;
4. Laboratory tests and further refinement or modification of the prototype; and
5. Field tests to evaluate and validate the effectiveness and efficiency of the new tool in breaking and removing concrete pavement.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

Based on the results, a prototype tool will be fabricated and made available for testing and evaluation by state highway agencies. The investigator will be given an opportunity to meet with U.S. highway engineers from state agencies for potential field trial testing of repair tools developed by the POTOK Centre. The results of this research from the Ukraine will be reported in an NCHRP-IDEA program report.

---

[1]The IDEA project is currently under negotiation. The IDEA project advisor will be Raymond Decker, University Science Partners, Ann Arbor, Michigan.
[2]Professor and Head, Department of Rock Fracture, Institute of Superhard Materials.
[3]Director, Engineering Information Centre, POTOK Centre.
[4]Professor, Institute of Superhard Materials.

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate the information produced by the research, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 330 committees, task forces, and panels composed of more than 3,900 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

NON-PROFIT ORG.
U.S. POSTAGE
PAID
WASHINGTON, D.C.
PERMIT NO. 8970

TRANSPORTATION RESEARCH BOARD
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Address Correction Requested

NATIONAL ACADEMY PRESS