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Implementation of Weigh-in-Motion (WIM) Systems

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HERE IS THE PROBLEM

A fundamental question to be answered by this research is: Are piezoelectric ceramic materials, which generally have a stable response over a large temperature range, feasible as a weigh-in-motion (WIM) traffic data sensor in spite of their inherent brittleness?

Currently, WIM systems use a piezoelectric polymer sensor that produces a voltage proportional to an applied pressure or load. Using this phenomenon, these systems are already being used to collect traffic data, including weigh-in-motion, measuring vehicle speeds, classifying vehicles by category and counting axles etc. The piezoelectric polymer sensors are usually in the form of a long tape or cable embedded within a long block of elastomeric material. These blocks are installed into grooves, which are cut into roads perpendicular to the traffic flow. The principal disadvantage of the present sensor technology is that the piezoelectric output is not uniform with temperature and time, thus leading to large uncertainty in the data collected.

AND, HERE IS THE SOLUTION…

Piezoelectric ceramic materials have a much more stable response over a large temperature range. However, bulk ceramics are not used for traffic data sensors due to their inherent brittleness.

Piezoelectric ceramic-polymer composites are made with an active piezoelectric ceramic embedded in a flexible non-active epoxy polymer. It was the intention of this work to utilize them for WIM applications by exploiting their flexibility and excellent piezoelectric properties similar to that observed in bulk ceramics.

There are many factors that can affect the accuracy of a WIM system. The effect of the factors is variable, and complex interactions among the factors can occur. The net effect of all the factors at any given time is the main issue for the development of the piezoelectric ceramic-polymer composite WIM system. Each system has an associated level of accuracy – in terms of a tolerance and conformity. Therefore, it was the goal of this work to develop a sensor with a higher level of accuracy than can be attained by available WIM systems under actual field conditions.

THESE ARE OBJECTIVES OF THE STUDY…

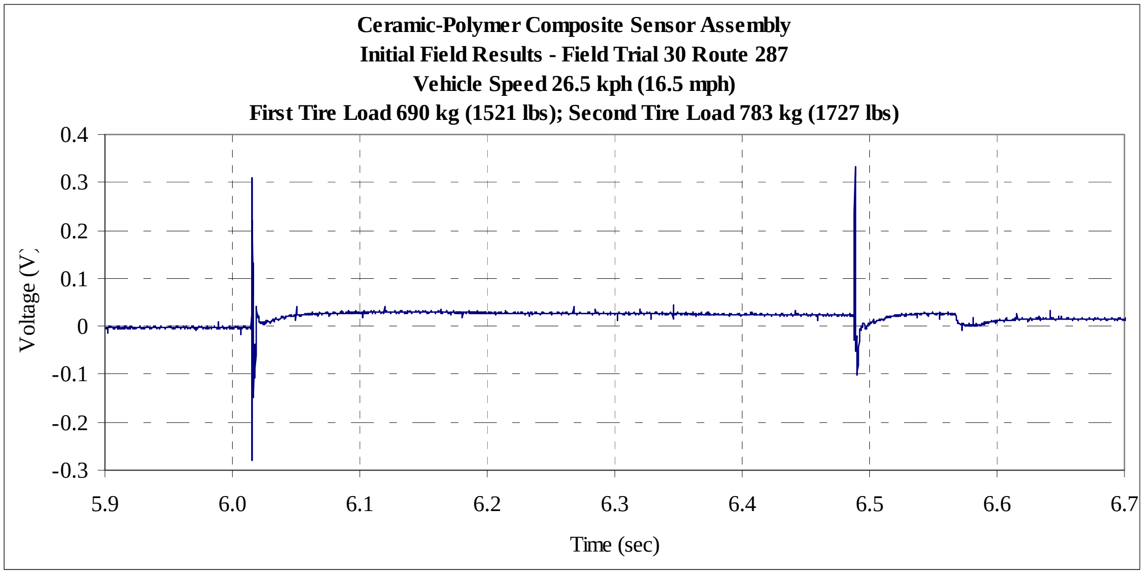
The goal of this research effort was to develop a sensor with a higher level of accuracy than can be attained by available WIM systems under actual field conditions. A recent NCHRP Study Synthesis 386, published in 2008, conducted a nationwide survey of all 50 States, DC, and Puerto Rico. One of the survey questions was "In your opinion, what are the most urgent WIM technical needs at present and what studies need to be conducted to address them?" However in general, respondents wanted more accurate, more durable, and less temperature dependant sensors as well as better epoxies/grouts to ensure installations last longer. Some of the comments were "better, more reliable sensors. Better epoxy," "making the BL piezos last longer regardless of what kind of traffic," "BL piezos are temperature and speed sensitive," "develop more accurate sensors," "Better grouts for piezos," "type II WIM perspective sensors are still the weak link," and finally to summarize the general consensus of the survey "sensors and installation methods that last." (NCHRP 386 2008) This research effort focused specifically on these issues, and thus this recent survey validates the national need the work performed.

HERE IS WHAT WE DID…

Piezoelectric ceramic-polymer composite sensor assemblies were fabricated for use as WIM sensors for measuring large loads. A complete review of the system characterization was conducted; which evaluated the active sensor themselves and the packaging and epoxy used to embed them in the roadway. Once the system characterization effort was complete, the ceramic-polymer composite sensor assemblies were installed on a full-scale highway Rt. 287 test scenario in order to perform actual measurements. The output was evaluated and a forensic review of the material was conducted to determine potential issues and develop future criteria to be further researched.

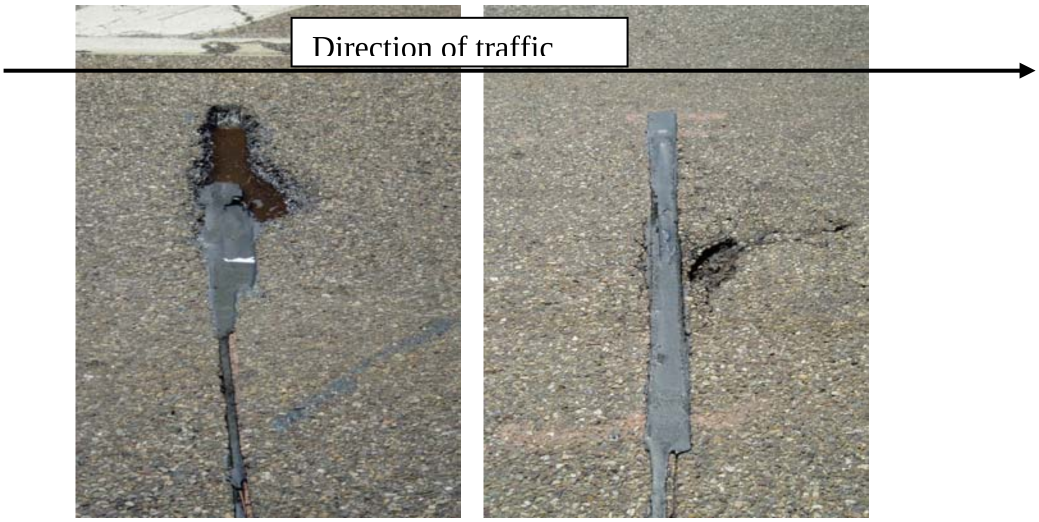
Photograph of the completed WIM installation at the Route 287 weigh station.

The research effort broadly consisted of long-term durability testing, field installation, field testing and analysis, and forensic evaluation. The main task of the research was to develop a longer lasting and more accurate sensor. This was accomplished by evaluating the performance of the final design by using accelerated loading tests in the laboratory. Since the sensor performed well under this durability testing, full scale implementation was conducted. The implementation of the sensor(s) was the ultimate goal of this project. Once the site was determined, the sensor(s) were installed on the ramp of a weigh station. The ceramic-polymer WIM systems were installed on a roadway and subjected to traffic. During that time period, data was collected.



Ceramic-polymer composite sensor assembly initial field trial Rt. 287 results at 26.5 kph (16.5 mph).

Less than seven months after installation (and only one season of winter effects), during a routine visit to the field installation it was discovered that the ceramic-polymer composite sensor assembly had failed. One assembly was partially torn and missing from the pavement; the other assembly was still intact, however it was showing signs of delamination. Both ceramic-polymer composite sensor assemblies can be seen below. The outside lane sensor had quite a drastic failure; water can be seen accumulating in the hole that was formed.



Failure of sensor assemblies; outside of lane (left) and inside of lane (right).

The entire ceramic-polymer composite sensor assembly from the inside lane was recovered. A portion of the outside lane sensor was also recovered, pieces of that sensor were found strewn throughout the roadway. A significant portion of these pieces, many of them being chunks of PZT composite, were also recovered. The recovered sensor assemblies were removed from the roadway by hand, simply by pulling up on the epoxy; thus demonstrating how weak the bond between the sensor and the roadway had degraded to. Since the inside lane sensor assembly was recovered largely intact it can be assumed that all sensor degradation would have been as a result of the damage experienced while installed on the roadway and not during the removal process. The entire sensor as removed from the field can be seen below.

Recovered sensor assembly from Rt. 287 field installation

WHAT IS THE NEXT STEP?

- Concerning the electroding, it is thought that a pre-encapsulation in a rigid elastomeric block may help to ensure the electroding remains affixed to the active material. In addition, the roadway epoxy is somewhat permeable (PU-200 has a water absorption rate of 2.5% as per the manufacturer) therefore if the active material is encased in an impermeable block the electrode as well as the sensor will be impervious to roadway salts and acids.
- The APA rut testing was extremely useful in selecting an epoxy for use. However, there is still much that is not known about how the epoxy interfaces with the roadway and the differences between a pure delamination and a delamination due to asphalt debonding. It is recommended to install a series of epoxies on a highway and observe the outcome without maintenance. All the epoxies (lets say five installations of each) could be installed on the roadway so they experience identical loading and then monitored for a period of time. Core samples could be taken of the pavement to verify material properties of the surrounding roadway. In addition non destructive testing such as GPR could be conducted on the segments to determine if there are any measureable pre-indicators of failure and maybe gain some insight into the exact failure mechanisms.

CONCLUSION…

From the System Characterization -Advanced Prototype Development (Packaging and Epoxy Selection) effort using the APA rutting evaluation no epoxy can be determined as clearly superior. Ranking was done considering the following priorities:

1. did not have actual epoxy cracking (longitudinal cracking);
2. nor demonstrated rigidity (significant protrusion from the sample surface;
3. nor flash point concerns;
4. nor long wait times until traffic ready;

PU-200 appeared to be the best compromise based on the APA rut testing, with no catastrophic failure nor significant material or handling concerns that had the least measured delamination. However this does not mean that PU-200 truly outperformed the other epoxies.

From the final laboratory and field trials and analysis effort it was shown that the widely held belief that WIM's installed in concrete will perform better because the visco-elastic asphalt variability is removed among other reasons, was not correct. By comparing the asphalt and the concrete samples for the same sample sets it clearly showed that the asphalt sample has a much lower standard deviation earlier. In addition, after seven months the sensor assemblies installed in the field still functioned, but the output voltages were diminished by 66% to 83% of that of the original voltage output. Similar residual stress patterns and other trends were still observed but for all intents the sensor assemblies were considered failed.

In summary, the ceramic-polymer composite sensors performed extremely well in all laboratory testing. However, under full-scale field implementation, a rather aggressive goal, the sensors and sensor assemblies experienced some level of failure. From the visual inspection it was clear that the cause of packaging failure is both a pure delamination of the asphalt-epoxy interface as well as a general delamination of the asphalt itself. Therefore the system characterization question of packaging remains. Also, as the roadway materials lose additional stiffness the asphalt pavement will begin to soften even more and have even higher load concentrations on the sensor itself, which might explain why there was localized cracking in the Rt 287 sample within the active ceramic sensor material itself. At some point the load concentration will cause the active "brittle" ceramic material to fail. Therefore, since the Rt. 287 pavement was already quite old and significantly fatigued the test site was prone to fail almost immediately after installation. Future installation should only be installed in asphalt pavement that is in good condition with significant remaining useful life.

Finally, once the above items are addressed a new full-scale field implementation could be conducted to re-evaluate the ceramic-polymer composite sensor assemblies. The field installation must be performed in a good quality pavement with significant remaining useful life; it is strongly believed that one of the primary reasons why the Rt. 287 full scale field installation failed, was simply due to poor pavements that have fatigued well beyond their useful life.

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A final report is available online at
http://www.state.nj.us/transportation/research/research.html
If you would like a copy of the full report, please FAX the NJDOT, Division of Research and Technology, Technology Transfer Group at (609) 530-3722 or send an e-mail to Research.Bureau@dot.state.nj.us and ask for**: Implementation of Weigh-in-Motion (WIM) Systems**

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