Proceedings of the 2010 Joint Rail Conference
JRC2010
April 27-29, 2010, Urbana, IL, USA

JRC2010-36215

POLYURETHANE COATING OF RAILROAD BALLAST AGGREGATE FOR IMPROVED PERFORMANCE

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ABSTRACT

This paper presents preliminary findings of a new technology currently being tested in a research project at the University of Illinois. The effectiveness of elastomer polyurethane coating of ballast is evaluated for its ability to reduce aggregate breakage and resulting ballast fouling. Railroad ballast degradation and fouling related to aggregate breakdown under heavy axle loads, poor drainage, mud pumping, and water/ballast pockets are among the most commonly encountered track substructure (ballast, subballast, and subgrade soil) problems. The structural integrity of seriously fouled ballast can be compromised leading to track instability and ultimately, train derailments. Because of this serious consequence, costly ballast maintenance activities, such as undercutting, tamping, and shoulder cleaning, are routinely performed by railroads especially on tracks serving the heavy axle load unit trains. In the research project, clean AREMA No.4 aggregates along with the polyurethane coated particles were subjected to realistic field loading conditions in a large shear box test apparatus used for strength testing of ballast at full gradation. The urethane coated ballast was allowed to set for 1, 3, 7, and 14 days prior to subjecting the samples up to 10 shear passes. Shear and normal stress data were gathered during testing; and the fines generated by all tested samples were collected and analyzed. Early findings show a major increase in the shear strength gained with the polyurethane coating, a decrease in the breakdown of the coated ballast, and a decrease in particle reorientation which could lead to a reduction in ballast settlement.

INTRODUCTION

A large portion of the annual budget to sustain the railway track system goes into maintenance and renewal of track ballast. Railroad ballast is uniformly-graded coarse aggregate placed between and immediately underneath the crossties. The purpose of ballast is to provide structural support for the heavy loading applied by trains. As ballast ages, it is progressively fouled with fine-grained materials filling the void spaces. Methods specifically used to assess track ballast condition only deal with checking visually for evidence of fouling, pumping and water accumulation (ponding) at ditches and shoulders. Some of these ballast problems, often conceived as routine, are primarily dealt with maintenance operations such as undercutting, ballast cleaning and removal, and tamping (Selig and Waters, 1994) When unnoticed, the structural integrity of seriously fouled ballast can be compromised leading to track instability and ultimately, train derailments.

A recent Association of American Railroads (AAR) industry survey of track substructure (ballast, subballast, and subgrade soil) performances conducted at the University of Illinois indicated that ballast degradation related fouling, poor drainage, mud pumping, and water/ballast pockets were the most commonly encountered substructure problems by the railroad companies. According to the survey results, site problems observed as a result of specifically the ballast fouling were poor drainage, cemented mass, pumping ties, center bound track, alignment deviations, subgrade shear failure, permanent deformations, and settlement from uneven support. Ballast sampling and testing for fouling through laboratory sieve analyses generally provide some insight into the compositions of the larger aggregate particles and the amount of fines. Nonetheless, for a better evaluation of the serviceability and proper functioning of the existing ballast layer, ballast strength and deformation behavior needs to be characterized in the laboratory and then linked to the field conditions.

Elastotrack® is a specially developed elastomer polyurethane system from BASF the Chemical Company's subsidiary Elastogran. The company is offering a novel plastic for reinforcing stone ballast for railroad track. Previous applications of such elastomer polyurethane, known as

Elastocoast®, have been focused on reinforcement of stone revetments for protecting dikes by absorbing the force of breaking waves and slowing down the water masses (Hicks et al., 2008). Polyurethane creates permanent and elastic bonds with stone to preserve the porous nature of the stone assembly to absorb energy and at the same time eliminate cracking that would normally occur with more rigid asphalt and Portland cement concrete solid revetments.

The idea of bonding railroad ballast stone using polyurethane plastics certainly has merit in railroad track stabilization and can extend track service lives especially in problematic zones such as turnouts and switches that require frequent ballast maintenance. Figure 1 shows a close-up picture of a freely draining polyurethane coated ballast specimen. By coating ballast particles sized up to 76 mm (3 in.) with polyurethane, typically achieved by mixing two types of polymers in tumblers, the stability and durability if the ballasted track can be improved. The major advantages are envisioned as increased load taking ability or shear strength properties and reduced breakdown or powdering potential of the individual contacting stone that carry the wheel load.

Figure 1 - Structure of polyurethane coated ballast that is freely draining.

The objective of this paper is to present the preliminary findings of the laboratory testing of the polyurethane coated ballast performed at the University of Illinois. The experimental program section covers the materials used, testing procedures followed, and the early results obtained from the direct shear tests on the strength increase and reduction of powdering potential of the glued aggregate particles.

EXPERIMENTAL PROGRAM

The following sections discuss the materials used and the testing procedures followed in the experimental program.

Ballast

Railroad ballast is uniformly-graded coarse aggregate placed between and immediately underneath the crossties. The purpose of ballast is to provide drainage and structural support for the heavy loading applied by trains. Aggregate particle shape and size distribution (gradation) are two major considerations in ballasted railroad track design. Superior ballast aggregate shape properties such as by an angular crushed stone have been proven to be critical for ballast strength and stability (Tutumluer et. al., 2006).

The ballast material tested was a limestone aggregate obtained near Paducah, Kentucky and commonly used in railroad track structures as the ballast layer. The grain size distribution of the limestone sample tested was in compliance with ASTM procedure. The limestone aggregate size distribution conforms to the typical AREMA No. 4 ballast gradation having a maximum size (D_{max}) of 50.8 mm (2 in.), a minimum size (D_{min}) of 12.7 mm (0.5 in.).

Polyurethane

Polyurethane is a hydrophobic two component polyurethane system which is 50% natural oil based components. Isocyanate and resin are mixed together to create a polyurethane mixture that typically gels within 30 to 60 minutes, yet can gel as quickly as one would prefer if chemically engineered too. Once gelling occurs, the contact points of the ballast bond together creating a strong ballast polyurethane matrix. Within 24 hours the structure is resilient and stable, and within 48 hours the polymer has reached its final hardness (Hicks et al., 2008). The polyurethane continues to gain strength for approximately 28 days. The completed structure is open pore which provides several advantages such as stability to freeze thaw cycles, permeability, and the dissipation of impact energy from waves in the previous Elastocoast application (Hicks et al., 2008).

Polyurethane contains 50% renewable resource content in the form of modified, natural, fatty acid based oils, which imparts hydrophobicity to the mixed polyurethane that actually allows the composite to cure underwater without a significant decrease in compressive strength.

An extensive study conducted by Hamburg-Harburg Technical University in Germany indicated that a significant weakening of the polyurethane is not expected from long term exposure to UV (Hicks et al., 2008). Furthermore, because the polyurethane ballast matrix is freely draining, freeze thaw cycles can occur without any significant deterioration in performance.

Direct Shear Apparatus

Figure 2 shows the large shear box equipment used for direct shear testing at the University of Illinois (Tutumluer et al., 2008; Dombrow et al., 2009). The test device is a square box with side dimensions of 305 mm (12 in.) and a specimen height of 203 mm (8 in.). It has a total 102 mm (4-in.) travel of the bottom which is a 152-mm (6-in.) high component, large enough for ballast testing purposes to record peak shear stresses. The vertical (normal direction) and horizontal load cells are capable of applying and recording up to 50-kN load magnitudes. The device controls and the data collection are managed through an automated data acquisition system controlled by the operator through a build-in display and the test data are saved on to a personal computer.

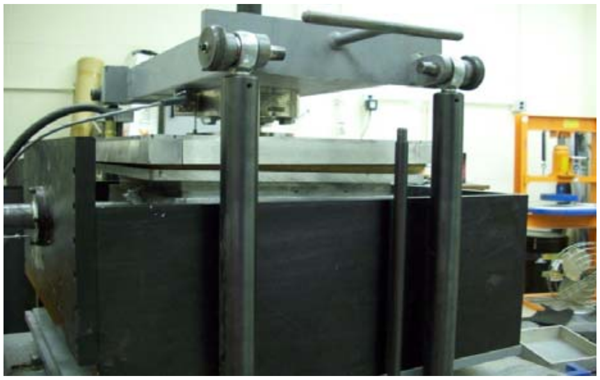

Figure 2 - Direct shear strength test equipment at the University of Illinois.

Test Procedure

1. Obtain two buckets of ballast aggregate, each weighing 18.1 kg (40 lbs).
2. Obtain and mix proper weights of isocyanate and resin to create the polyurethane used to coat the ballast.
3. Introduce polyurethane to a bucket of aggregate and mix until ballast is completely covered.
4. Compact ballast sample into lower box (356 mm x 305 mm x 152 mm or 14 in. x 12 in. x 6 in.) using two 76 mm (3 in.) lifts. Use vibratory compactor on top of a flat Plexiglas compaction platform and compact until no noticeable movement of particles is observed.

Figure 3 - Stages of ballast preparation, compaction, and loading upper ring.

5. Repeat steps two and three, and then place upper ring (76 mm or 3 in. high) on top of lower box. Align ring with sides and back edge of box (opposite of block) and fill with single lift of ballast and compact (see Figure 3).
6. Place box and ring assembly into shearing apparatus. Clamp lower box in place. Place load bearing plate on ballast and inside upper ring. Place air-bladder on bearing-plate. Close normal force load cell over air-bladder. Open air supply and set pressure using an in-line pressure regulator (see Figure 3).
7. Adjust shear force load cell directly against the upper ring.
8. Prepare LabVIEW Data Logger software to record normal and shear force while the test is running.
9. Input shear rate of 12.2 mm/min. (0.48 in./min.) which is approximately 4% strain per minute and run test until shear force output becomes constant or 15% strain has occurred.

Shear Strength Test

Shear strength tests were performed on unbound ballast aggregate as well as the polyurethane coated ballast specimens. The shear strength test was conducted to assess the apparent strength gain from the application of polyurethane to ballast.

The direct shear strength tests were performed on unbound ballast aggregate at 1-day, 3-day, 7-day, and 14-day set times of polyurethane coated ballast with each test applying two normal pressures, 172 and 241 kPa (25 and 35 psi), for a total of ten tests.

Powdering Test

Powdering tests were performed on new unbound ballast as well as the polyurethane coated ballast specimens by repeatedly shearing the specimens for a total of ten times. The objective of the powdering tests was to assess the amount of aggregate breakage and degradation, i.e., fouling potentials, due to breakdown of new unbound and polyurethane coated ballast.

Powdering tests were performed on unbound ballast materials, as well as the 1-day set and 7-day set polyurethane coated ballast aggregate with each test applying at two normal pressures, 172 and 241 kPa (25 psi and 35 psi), for a total of six tests.

PRELIMINARY TEST RESULTS AND DISCUSSION

The following sections present the preliminary results obtained from the shear strength and powdering tests on both unbound and polyurethane coated ballast aggregates. A brief discussion of these results is also presented.

Shear Strength Test

The ballast samples were sheared horizontally in the shear box under target normal pressures of 172 and 241 kPa (25 psi and 35 psi), typical ballast layer confining pressures. Maximum shear stress levels reached and the horizontal displacements recorded are indicated in Figure 4.

As expected, the unbound aggregate resulted in the lowest maximum shear stress (i.e., strength) at 331 kPa (48 psi) and 400 kPa (58 psi) when confined at 172 and 241 kPa (25 and 35 psi), respectively. The longer the polyurethane was cured, the stronger the specimens became. The strongest was the 14-day cured specimen which reached up to 726 kPa (105 psi). This corresponds to almost a doubling of the strength when compared to the unbound specimen tested at 241 kPa (35 psi).

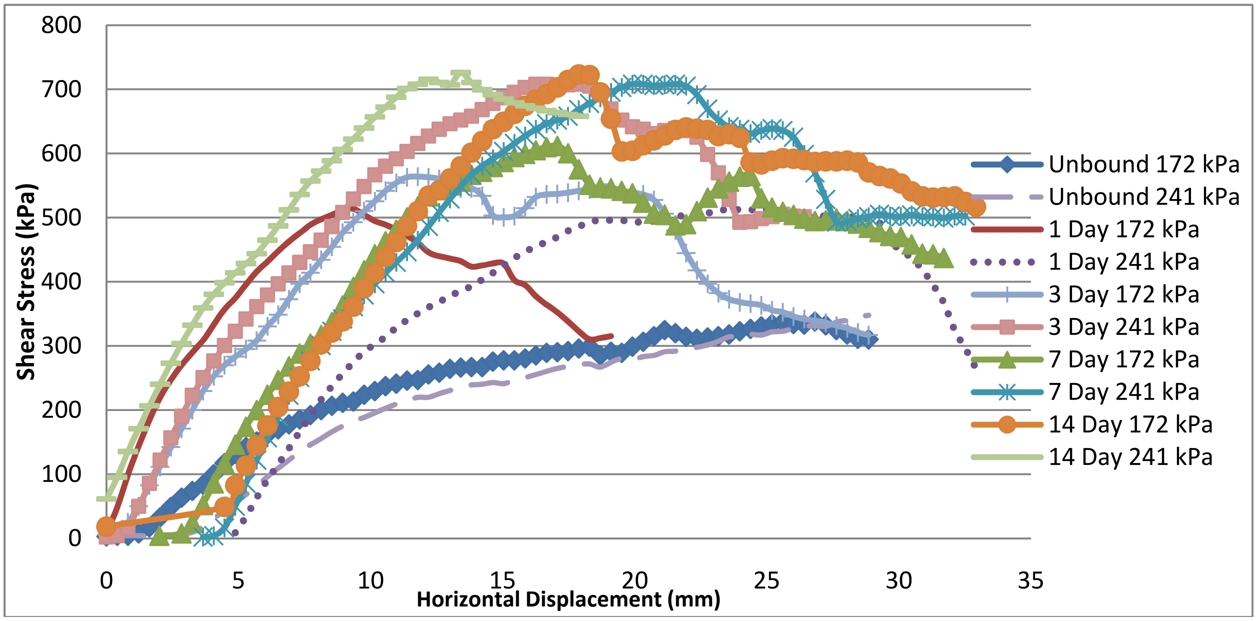

Figure 4 – Maximum shear stresses graphed with horizontal displacements from direct shear testing.

Powdering Test

The ballast samples were sheared horizontally in the shear box under target normal pressures of 172 and 241 kPa (25 psi and 35 psi), typical ballast layer confining pressures. Unbound samples as well as the 1-day and 7-day cured ballast materials were each sheared ten times to simulate very harsh shearing effects in the field, e.g., many load applications from actual train loading over a long period of time. After shearing was completed, all particles were collected and sieved to obtain the size distributions after powdering.

Figure 5 shows the gradations of the two powdering tests on unbound aggregate samples and the original gradations of the new ballast from the stockpile. As expected there is a greater amount of smaller particles or fines after powdering. Specifically, for the percent passing 25-mm (1-in.) sieve, after powdering there is a 15% increase in particles passing the 25 mm (1 in.) sieve when a normal pressure of 241 kPa (35 psi) is applied.

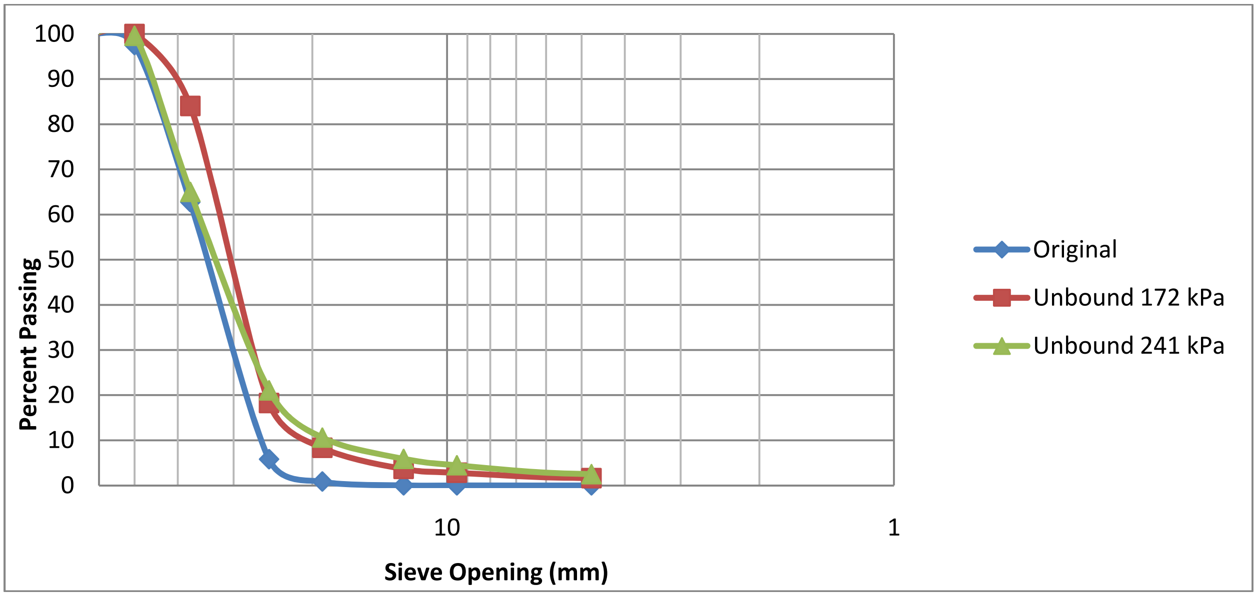

Figure 5 - Gradations of unbound aggregate particles recovered after powdering test.

Table 1 and Figure 6 show the percentages retained on each sieve of each powdering test performed. Before performing the tests, it was ensured that there were no particles smaller than 13-mm (1/2-in.) size to create a baseline of measurement. Therefore, the values presented are those only passing the 13-mm (1/2-in.) sieve because the polyurethane coated ballast specimens were still glued and unable to be sieved even after shearing. It is evident that the polyurethane coated specimens created significantly fewer fine particles than the unbound specimens.

Table 1 – Comparisons of percentages retained on each sieve after powdering of unbound and polyurethane coated ballast aggregates.

Sieve (mm)	Percent Retained on Each Sieve					
	Polyurethane Coated Aggregate				Non-Coated Aggregate	
	1 Day, 172 kPa	1 Day, 241 kPa	7 Day, 172 kPa	7 Day, 241 kPa	Unbound, 172 kPa	Unbound, 241 kPa
9.51	0.15	0.38	0.43	0.36	0.84	1.41
4.76	0.20	0.43	0.59	0.49	1.19	1.97
0.075	0.21	0.53	0.58	0.63	1.29	2.30
Pan	0.01	0.02	0.01	0.03	0.33	0.19
Total	***0.58***	***1.36***	***1.61***	***1.51***	***3.66***	***5.87***

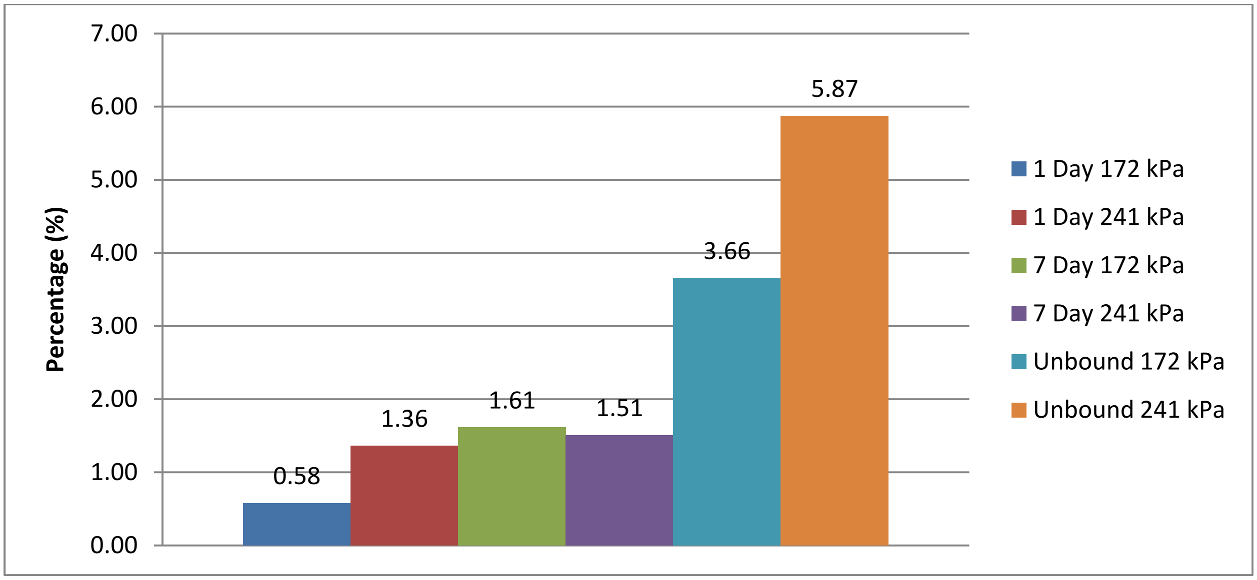

Figure 6 - Comparisons of percentages retained on each sieve after powdering of unbound and polyurethane coated ballast aggregates.

Preliminary results also indicate that polyurethane coated ballast particles will fracture similar to unbound ballast, however, they will not breakdown as much as the unbound ballast particles because of the glue provided by the polyurethane matrix. The broken ballast particles remain intact (see Figure 7). This may lead to an aggregate matrix that would not easily reorient itself under repeated applications of train loading, which could altogether result in less breaking and fouling. Because of reduced particle reorientation, when the polyurethane coated ballast specimen was removed after testing, it usually came out of the shear box as a single block (see Figure 8). The block removed was still porous and allowed the free flow of water. The free flow of water is very important since this is the main function of the ballast layer. Accordingly, the polyurethane coated ballast would be freely draining just like a newly placed unbound aggregate ballast layer.

Figure 7 - Broken ballast still remained within the matrix via polyurethane coating.

Figure 8 - Single block removed from direct shear test apparatus after shearing.

An added benefit that could occur due to the reduction in ballast breakdown is the decrease in ballast settlement, which is in fact quite important as the track would require less geometry related maintenance. This would in turn reduce the frequency of a line needing to undergo tamping or undercutting and the need for less track time by maintenance crews would allow maintaining the overall track speed with fewer train slow orders.

SUMMARY AND CONCLUSIONS

A new technology for construction of railroad track substructure dealing with polyurethane coating of ballast aggregate has been introduced and tested at the University of Illinois. The large direct shear box apparatus was used to perform shear strength and powdering tests on both new clean (unbound) and polyurethane coated aggregate specimens. Preliminary results are quite positive thus far. The polyurethane coated ballast has significantly higher shear strength than unbound ballast. This is promising since the increase in shear strength could result in applications of installation of the polyurethane coated ballast at switches, turnouts, or any other heavy maintenance, high impact areas that usually undergo frequent ballast cleaning or replacement due to increased ballast breakdown.

More and detailed testing will need to be performed to further verify these promising preliminary results. Future testing will focus on the development of shear strength components for the polyurethane coated ballast samples using the direct shear apparatus and testing at other normal pressure levels. The contribution of cohesion to the shear strength due to the glue will be assessed in relation to frictional properties. Future research will also investigate the effects of using different chemical compositions of the polyurethane to allow greater strain before failure, which would potentially result in fewer fines generated from powdering tests.

ACKNOWLEDGEMENTS

The authors would like to thank BASF the Chemical Company for providing the financial support and the polyurethane materials needed to carry out this research study. The limestone ballast aggregate was provided for this study by the Burlington Northern Santa Fe (BNSF) Railroad Company and the authors appreciate all the help and collaboration of Mr. Hank Lees with BNSF. The authors would also like to thank Anthony Mareno for his assistance in the setting up and running of the direct shear tests at the University of Illinois.

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