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Analysis on Mechanical Characteristics of the Polyurethane Base Plate for Ballastless Track of High Speed Railway

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In this paper, test method is used in giving tensile strength test, elongation at break test, permanent compressive deformation, oil resistance test and dynamic and static stiffness test to the aging and non-aging polyurethane base plates, and it is used in analyzing influence of the mass ratio of bi-functional and tri-functional mixed polyethers on the relevant mechanical characteristics of polyurethane elastic base plate. The research conclusions indicate that: when using polyurethane in potting filling of the gap between track and concrete roadbed, the high-speed roadbed shall seldom show subsidence and deformation; when not giving potting filling, the whole railway ballast shall show a subsidence about 50mm after 100,000 times of cyclic loading, and the deformation shall be very serious, which could indicate the obvious effect of the potting filling of polyurethane. When tri-functional mixed polyether has the maximum proportion, the polyurethane base plate before aging and the non-aging polyurethane base plate shall all have the maximum tensile strengths and the minimum compressive deformation of 2.91%. Along with increment of the proportion of bi-functional mixed polyether, tensile strength of polyurethane base plate shall reduce gradually, and elongation at break of polyurethane base plate shall increase continuously. 20:80 proportions of bi-functional and tri-functional mixed polyethers can be used as design standard of the polyurethane base plate.

1. Introduction

High speed railway has become the main daily travel mode of the people, and the characteristics of comfortable environment, high speed and punctuality make for rapid development of the high speed railway industry. The vibration between train and track is the main factor affecting safety and comfort of the high speed train. If the caking ability between track and concrete roadbed is insufficient, or track laying is uneven, it shall be easy to cause aggravated train vibration and the increment of tensile stress, shear stress, tensile strength and compressive deformation of the track, which might result in damage of track and even such serious accidents as train derailment, as well as huge personal and property loss (Ishida et al., 2008; Newton and Clark, 1979; Remennikov and Kaewunruen, 2006; Madshus and Kaynia, 2000).
It is the factor needing to be considered preferentially in high speed railway design to increase caking property and stability of track and concrete roadbed. Ballast track was widely used in high speed railway construction in the past, while it showed such problems as insecure caking of track and concrete roadbed, railway ballast splashing and further acceleration of the high speed rail. Ballastless track is the high speed rail structure appeared in recent years, and it possesses such advantages as stable structure, small deformation and strong compression resistance ability (Jong-Shyong and Shih, 2000; Xiao et al., 2007; Jenkins et al., 1974; Zakeri, Fathali and Nima, 2013; Gialleonardo, Braghin and Bruni, 2012; Li et al., 1999; Cui et al., 2015; Woodward et al., 2012).
Polyurethane material is a kind of high molecular chemical polymer, and it has such characteristics as favorable vibration reduction, wear resistance and compression resistance. It has been used in filling the gap between high speed track and concrete roadbed as filler, and it can not only provide extra elastic force but also repair defect and deformation of track or concrete roadbed (Woodward et al., 2012; Oprea et al., 2007; Woodward et al., 2012; Woodward, Laghrouche and El-Kacimi, 2014).
In this paper, test method is used in giving tensile strength test, elongation at break test, permanent compressive deformation, oil resistance test and dynamic and static stiffness test to the aging and non-aging

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polyurethane base plates, and it is used in analyzing influence of the mass ratio of bi-functional and tri-functional mixed polyethers on the relevant mechanical characteristics of polyurethane elastic base plate.

2. Application of Polyurethane in High Speed Rail Construction

Being as the advanced composite material, polyurethane has already been used in filling the gap between high speed track and concrete roadbed as filler, and it can not only provide extra elastic force but also repair defect and deformation of track or concrete roadbed. Potting filling mechanism of polyurethane is as shown in Figure 1.

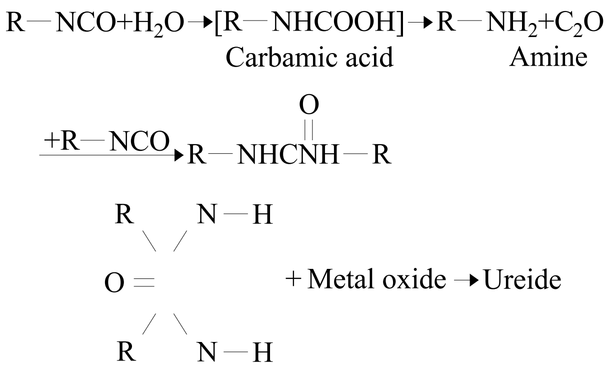

Figure 1: Chemical Mechanis of Munballasted Track Potting Filling

Potting filling of polyurethane is also called railway ballast caking, which possesses simple caking principle and strong practicability. When potting the filler gum in the gap between track and concrete roadbed, the track and roadbed shall become to an integral whole gradually along with continuous penetration of filler gum, thus anti-deformation ability, stiffness and compression resistance ability of ballast bed could be promoted greatly. Figure 2 shows the three-dimensional high speed track model established, and it compares track subsidence in conditions of giving and not giving polyurethane potting filling via several times of load. It can be seen from the figure that: when using polyurethane in potting filling of the gap between track and concrete roadbed, the whole high-speed roadbed shall seldom show subsidence and deformation after 500,000 times of cyclic loading continuously; when not giving potting filling, the whole railway ballast shall show a subsidence about 50mm after 100,000 times of cyclic loading, and the deformation shall be very serious, which could indicate the obvious effect of the potting filling of polyurethane.

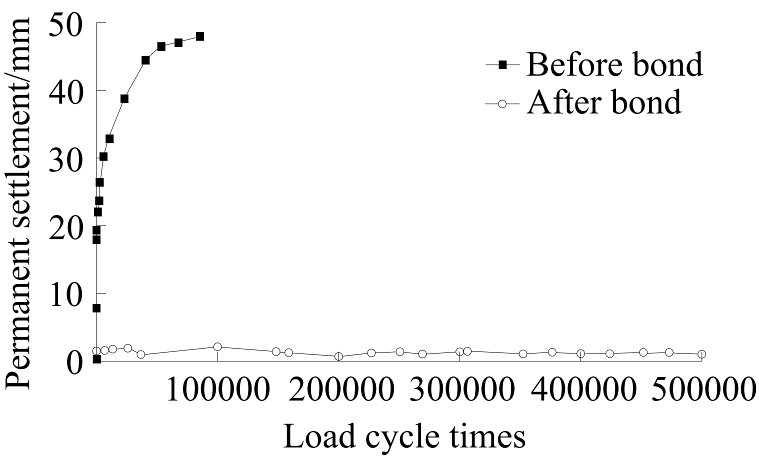

Figure 2: Effect of Ballast Bond on Roadbed Subsidence

3. Applied Analysis of the Elastic Base Plate for Ballastless Track of High Speed Railway

In recent years, ballast track is gradually replaced by ballastless track. Being as new structural style of the high speed rail, ballastless track possesses such advantages as stable structure, small deformation and strong compression resistance ability. Polyurethane elastic base plate is a typical ballastless track base plate, and test method can be used in analyzing influence of the mass ratio of bi-functional and tri-functional mixed polyethers on the relevant mechanical characteristics of polyurethane elastic base plate.

Main materials of the test are polyethers A-F, and *f* and hydroxyl value are different. Tri-functional mixed polyether (F3) can be obtained by mixing polyethers A-C with same proportions, and bi-functional mixed polyether (F2) can be obtained by mixing polyethers D-F with same proportions. Afterwards, one can add butanediol, distilled water and catalyst in the two solutions, set ambient temperature of the solutions as 40□ and stirring speed as 9,000r/min, conduct demoulding, give curing for 4h after 18h of standing, and place them in normal temperature environment for use.

Tensile strength test, elongation at break test, permanent compressive deformation, oil resistance test and dynamic and static stiffness test shall be given to the two groups of test pieces, and expressions of dynamic stiffness K_{DYN} and static stiffness K_{STA} are as follows:

$$\begin{cases} K_{STA} = \dfrac{F_2 - F_1}{D_2 - D_1} \\ K_{DYN} = \dfrac{F_{2a} - F_{1a}}{D_4 - D_3} \end{cases} \tag{1}$$

F_1, F_2, F_{1a} and F_{2a} refer to the loads applied, and D_1-D_4 refer to rail displacements. Aging test is given to a part of the test pieces, with test temperature 110□ and test time 100h.

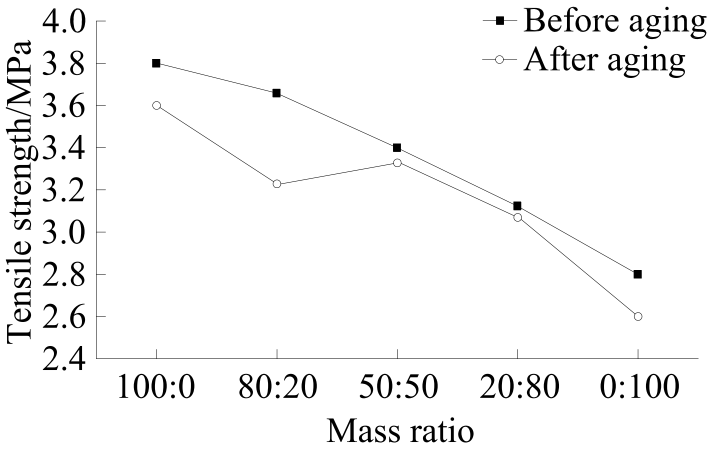

Figure 3: The Effect of Different Functionality Blended Polyether Mass Ratio on Tensile Strength

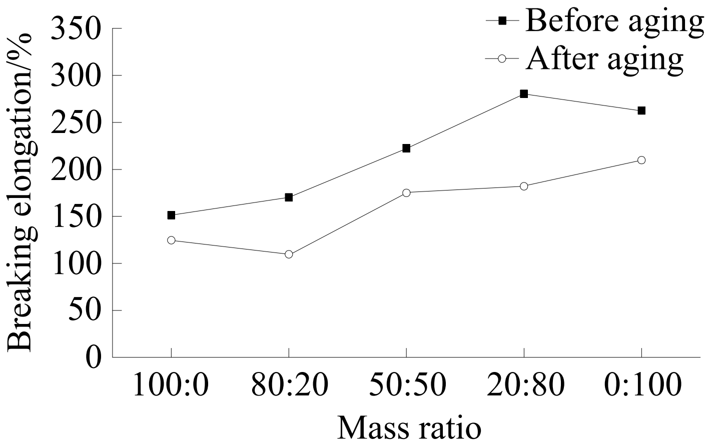

Figure 4: Effect of Different Functionality Blended Polyether Mass Ratio on Breaking Elongation

Figure 3 shows comparison of the tensile strengths of new polyurethane base plate and aging polyurethane base plate in the five conditions with mixing ratios of tri-functional and bi-functional mixed polyethers as 100:0, 80:20, 50:50, 20:80 and 0:100 respectively. It can be seen fro the figure that: when the additive is tri-functional mixed polyether wholly, the polyurethane base plate before aging and the non-aging polyurethane base plate shall all have the maximum tensile strengths, and tensile strength of polyurethane base plate shall reduce gradually along with increment of the proportion of bi-functional mixed polyether, for decrement of crosslinking density of the base plate caused by increment of the proportion of bi-functional mixed polyether. Tensile strength of the aging polyurethane base plate is lesser than that of the non-aging base plate, for damage of the internal structure caused by aging of base plate.
Figure 4 shows elongation at break of the mixture with different mixing proportions of tri-functional and bi-functional mixed polyethers. It can be seen from the figure that: elongation at break of the polyurethane base plate increases continuously along with increment of the proportion of bi-functional mixed polyether, and elongation at break of the base plate after aging is lesser than that of the non-aging base plate, for increment of the internal molecule flexibility of base plate after increment of the bi-functional mixed polyether.

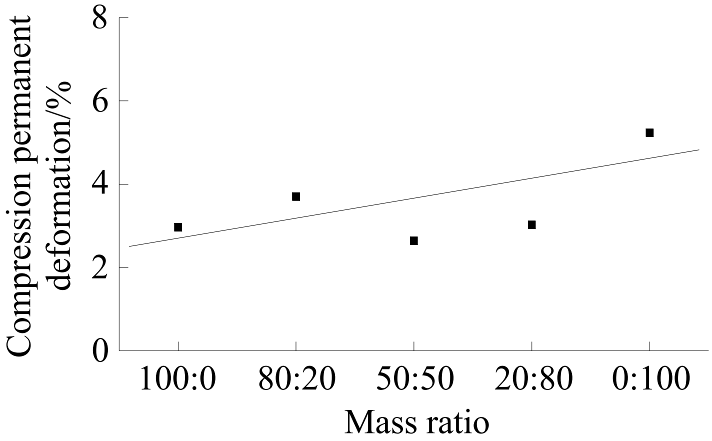

Figure 5: Effect of Different Functionality Blended Polyether Mass Ratio on Compression Permanent Deformation

Figure 5 shows compressive deformation characteristics of the polyurethane base plate with different proportions of the different functional mixed polyethers. It can be seen from the figure that: when additive is tri-functional mixed polyether wholly, polyurethane base plate shall have the minimum compressive deformation of 2.91%; when additive is bi-functional mixed polyether wholly, polyurethane base plate shall have the maximum compressive deformation of 5.52%, and compressive deformation of polyurethane base plate shall show linear growth trend along with increment of the proportion of bi-functional mixed polyether.

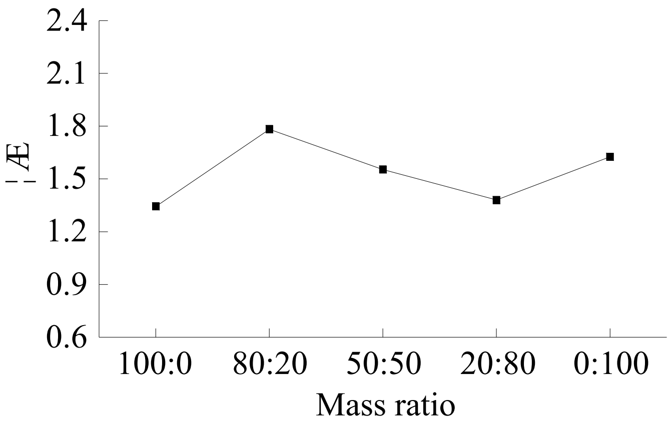

Figure 6: Effect of Different Functionality Blended Polyether Mass Ratio on Springrate Ratio

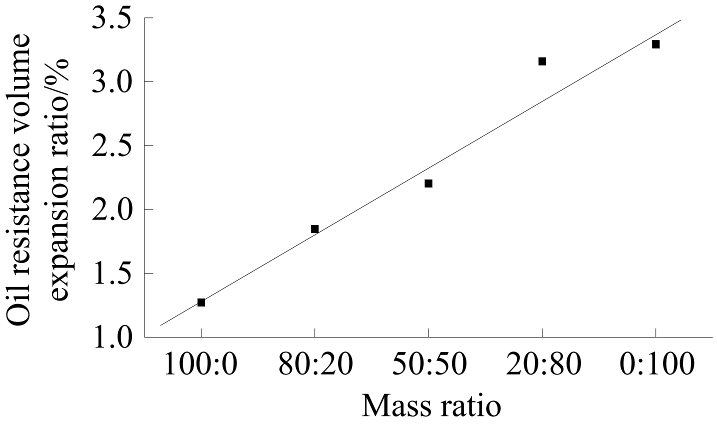

Figure 7: Effect of Mass Ratio on Oil Resistance Volume Expansion Ratio

Figure 6 shows dynamic and static stiffness ratio of polyurethane base plate with different proportions of the different functional mixed polyethers. In ideal conditions, the dynamic and static stiffness ratio is 1, and the larger value shall indicate the stronger vibration of train. It can be seen from the figure that: when the mixture is tri-functional mixed polyether wholly, or proportion of tri-functional and bi-functional mixed polyethers is 20:80, the dynamic and static stiffness shall be minimum, and vibration of train shall also be minimum by this time.

Figure 7 shows oil resistance expansion rate of polyurethane base plate with different proportions of the different functional mixed polyethers. When proportion of the tri-functional mixed polyether reduces gradually, expansion rate of polyurethane base plate shall increase gradually. When proportion of the tri-functional mixed polyether is zero, oil resistance expansion rate shall be maximum and reach 3.53%, for bi-functional mixed polyether can restrict slipping of molecular chain.

4. Conclusions

Test method is used in giving tensile strength test, elongation at break test, permanent compressive deformation, oil resistance test and dynamic and static stiffness test to the aging and non-aging polyurethane base plates, and it is used in analyzing influence of the mass ratio of bi-functional and tri-functional mixed polyethers on the relevant mechanical characteristics of polyurethane elastic base plate. Research conclusions are as follows:

(1) When using polyurethane in potting filling of the gap between track and concrete roadbed, the whole high-speed roadbed shall seldom show subsidence and deformation after 500,000 times of cyclic loading continuously; when not giving potting filling, the whole railway ballast shall show a subsidence about 50mm after 100,000 times of cyclic loading, and the deformation shall be very serious, which could indicate the obvious effect of the potting filling of polyurethane.

(2) When tri-functional mixed polyether has the maximum proportion, the polyurethane base plate before aging and the non-aging polyurethane base plate shall all have the maximum tensile strengths and the minimum compressive deformation of 2.91%. Along with increment of the proportion of bi-functional mixed polyether, tensile strength of polyurethane base plate shall reduce gradually, and elongation at break of polyurethane base plate shall increase continuously. 20:80 proportion of bi-functional and tri-functional mixed polyethers can be used as design standard of the polyurethane base plate.

Acknowledgments

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Reference

Cui X.L., Chen G.X., Yang H.G., Zhang Q., Ouyang H., Zhu M.H., 2015, Effect of the wheel/rail contact angle and the direction of the saturated creep force on rail corrugation, Wears, 330-331(3), 554-562, DOI: 10.1016/j.wear.2014.12.046.

Gialleonardo E.D., Braghin F., Bruni S., 2012, The influence of track modelling options on the simulation of rail vehicle dynamics, Journal of Sound & Vibration, 331(19), 4246-4258, DOI: 10.1016/j.jsv.2012.04.024.

Ishida M., Ban T., Iida K., Ishida H., Aoki F., 2008, Effect of moderating friction of wheel/rail interface on vehicle/track dynamic behaviour, Wear, 265(9), 1497-1503, DOI: 10.1016/j.wear.2008.02.041.

Jenkins H.H., Stephenson J.E., Clayton G.A., Morland G.W., Lyon D., 1974, The effect of track and vehicle parameters on wheel/rail vertical dynamic loads, Railway Engineering Journal, 3(1), 2-16.

Jong-Shyong W.U., Shih P.Y., 2000, Dynamic responses of railway and carriage under the high-speed moving loads, Journal of Sound & Vibration, 236(1), 61-87, DOI: 10.1006/jsvi.2000.2959.

Li D., Elkins J., Otter D., Wilson N., 1999, Vehicle/track dynamic models for wheel/rail forces and track response, International Journal of Heavy Vehicle Systems, 6(1/2/3/4), 345-359, DOI: 10.1504/ijhvs.1999.054641.

Madshus C., Kaynia A.M., 2000, High-speed railway lines on soft ground: dynamic behaviour at critical train speed, Journal of Sound & Vibration, 231(3), 689-701. DOI: 10.1006/jsvi.1999.2647.

Newton S.G., Clark R.A., 1979, An investigation into the dynamic effects on the track of wheelflats on railway vehicles, Journal of Mechanical Engineering Science 1959-1982, 21(4), 287-297, DOI: 10.1243/jmes_jour_1979_021_046_02.

Oprea S., Vlad S., Stoicescu G., Casariu M., 2007, Polyurethane elastomeric bearing materials for passive isolation of railway, Materiale Plastice, 44(3), 226-232.

Remennikov A., Kaewunruen S., 2006, Experimental investigation on dynamic railway sleeper/ballast interaction, xperimental Mechanics, 46(1), 57-66, DOI: 10.1007/s11340-006-5868-z.

Woodward P., Laghrouche O., El-Kacimi A., 2014, Railway track transition dynamics and reinforcement using polyurethane geocomposites, Geotechnical Engineering, 45(1), 28-38.

Woodward P.K., Kacimi A.E., Laghrouche O., Medero G., Banimahd M., 2012, Application of polyurethane geocomposites to help maintain track geometry for high-speed ballasted railway tracks, Journal of Zhejiang Universityence A, 13(11), 836-849, DOI: 10.1631/jzus.a12isgt3.

Woodward P.K., Kennedy J., Medero G.M., Banimahd M., 2012, Application of in situ polyurethane geocomposite beams to improve the passive shoulder resistance of railway track, Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail & Rapid Transit, 226(3), 294-304, DOI: 10.1177/0954409711423460.

Woodward P.K., Kennedy J., Medero G.M., Banimahd M., 2012, Maintaining absolute clearances in ballasted railway tracks using in situ three-dimensional polyurethane geocomposites, Proceedings of the Institution of Mechanical Engineers Part F Journal of Rail & Rapid Transit, 226(226), 257-271, DOI: 10.1177/0954409711420521.

Xiao X.B., Wen Z.F., Jin X.S., Sheng X.Z., 2007, Effects of track support failures on dynamic response of high speed tracks, International Journal of Nonlinear Sciences & Numerical Simulation, 8(4), 615-630, DOI: 10.1515/ijnsns.2007.8.4.615.

Zakeri J.A., Fathali M., Nima B.R., 2013, Effects of rail cant on wheel-rail contact forces in slab tracks, International Journal of Mechanics & Applications, 1(1), 12-21, DOI: 10.5923/j.mechanics.20110101.02.