Ballast of the future on Heavy Haul lines: Assessing the viability of Neoballast on the Coal line

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ABSTRACT: Ballast is a critical element of the superstructure of the track as it maintains the track stability. The maintenance of ballast is frequent and expensive due its constant degradation and the subsequent loss of track geometry. Neoballast is a new innovative ballast aggregate, developed by COMSA in Barcelona, that is coated with recycled rubber originating from recycled tyres. One of the main purposes of this new ballast is to reduce the stiffness of the track as well as to increase the abrasion resistance. Therefore, this study intends to investigate the viability of Neoballast on the Heavy Haul lines in South Africa in terms of its mechanical properties based on the minimum required specifications for Heavy Haul lines, as compared to the current ballast on the Coal line. Results from the Los Angeles Abrasion, Mill Abrasion, Soundness, and Water Absorption tests conducted, indicated that Neoballast provided more abrasion resistance, weathering resistance and less water absorption as compared to the current Coal line ballast. Thus indicating a reduction in ballast fouling which will result in a decrease in ballast layer settlement. Furthermore, the Neoballast indicated to be suitable for the Coal line. Neoballast will lead to a decrease in the deterioration of track geometry and economic costs of maintenance on Heavy Haul lines.

1. INTRODUCTION

Heavy Haul railway lines are subjected to high axle loads and in turn high dynamic stresses are imposed on the track. The tracks on South Africa's coal lines are subjected to 26 axle tons and haul approximately 108 million tons of coal each year. With the amount of tonnages increasing yearly, the load the track is subjected to increases proportionally. The ballast-sleeper interface is the area which experiences high contact stresses due to the passage of these trains (Gräbe, et al., 2016). The high contact stresses cause the sleeper to break the ballast particles which subsequently results in ballast degradation as well as the wear of the sleepers (Gräbe, et al., 2016). This thereby increases the rate of track deterioration since the ballast layer's ability to function optimally deteriorates. The deterioration of track geometry is a major problem on Heavy Haul lines (Askarinejad, et al., 2018). This requires frequent ballast replenishment as well as corrective maintenance to restore the track geometry, thus increasing the budget spent on maintenance due to ballast degradation. Therefore, the need for innovative ways to minimize the track geometry deterioration has become vital in recent years. The advantageous properties of utilizing rubber in aggregates have led to the development of a new and innovative ballast called 'Neoballast' (Valentí, et al., 2016). The aim of this new ballast is to improve the rate of degradation and settlement of the ballast layer, thereby reducing the deterioration of track geometry and budget spent on maintenance. Therefore, the aim of this study is to investigate the viability of Neoballast on the Heavy Haul line in South Africa in terms of its mechanical properties, based on the minimum required specifications for Heavy Haul lines in South Africa.

2. LITERATURE REVIEW

2.1 Importance of ballast

Ballast comprises of an angular coarse material and lies below the rail and sleeper of a track structure (Ciotlaus & Kollo, 2018). The ballast layer provides a load bearing layer that supports the track structure against the high dynamic forces exerted onto it by the passage of trains (Indraratnaa, et al., 2017). When the ballast layer is subjected to high cyclic loading, it undergoes deformation and settlement. According to Indraratnaa, et al., (2017), ballast has the following important functions: *"(i) transmitting induced loads to sub-layers at reduced and acceptable stress levels, (ii) providing lateral and longitudinal resistance and (iii) facilitating free* *drainage conditions"*. Ciotlaus & Kollo (2018) adds that ballast assists with the alignment of the track by maintaining the gauge of the sleepers. According to Claisse & Calla (2006), the angularity and material hardness of the ballast stone enables ballast to interlock without crushing. These properties provide optimal frictional resistance to prevent the movement of sleepers (Claisse & Calla, 2006). Ballast plays a vital role in the facilitation of maintenance of the track to correct the track geometry by permitting the use of the Tamping machine [Claisse & Calla (2006) and Nimbalkar, et al. (2014)]. Therefore, ballasted tracks are more favorable as compared to a non-ballasted track (Kumaraa, & Hayano, 2016). Thus, it is evident that the ballast layer is a critical element in the track structure.

2.2 Forces applied to the ballast

Cyclic loading due to the passage of trains as well as high impact loading at points of discontinuity on the track causes the ballast particles to break and lose its angularity (Indraratnaa, et al., 2017). The breakage of the edges of the ballast leads to ballast fouling (Kumaraa, & Hayano, 2016). Fouled ballast loses its interlocking properties between each other which decreases the shear strength capacity of the ballast layer (Indraratnaa, et al., 2017), thus consequently causing an adverse effect on the ability of the ballast to perform its required function. According to Indraratnaa, et al., (2017) and Kumaraa, & Hayano (2016), ballast replenishment costs due to the breakage of ballast and ballast fouling consumes a large percentage of the track maintenance budget. On the Coal line in South Africa, the ballast fouling index is 60% and the approximate cost of the ballast replenishment project is R 21 781 360,00 per year for a 1055 km track. With the increase in the amount of tonnages being hauled every year on the Heavy Haul line, the ballast will be subjected to increasing degradation which will lead to an increase in maintenance cost.

2.3 Ballast Fouling

When ballast is contaminated by accumulated fines smaller than 9.5milimeters (mm), it is considered to be 'fouled ballast' (Nimbalkar, et al., 2014). There are many causes of ballast fouling. On the Coal line the causes of ballast fouling are due to spillage of coal from the passage of coal trains, mud pumping and ballast degradation (Nimbalkar, et al., 2014). It is known that the main cause of ballast fouling is due to the degradation of ballast (Nimbalkar, et al., 2014). The breakage of ballast particles is caused by the high dynamic forces applied to it as well as when regular maintenance is conducted on the track by the Tamping machine (Claisse & Calla, 2006). According to Claisse & Calla (2006), the Tamping machine is the source of more than 50% of fouled ballast in the United Kingdom. Tamping is conducted to correct the track geometry, however in the process it breaks the ballast particles due to the pressure squeezing forces and vibration of the machine (Ciotlaus & Kollo, 2018). Therefore, this action diminishes the angularity of the ballast shape and subsequently increases the percentage of fines in the ballast layer (Ciotlaus & Kollo, 2018).

When 'un-fouled' ballast is placed in the ballast layer, the pressure between ballast aggregates and the sleepers help provide stiffness to the track, hence maintaining the track geometry (Askarinejad, et al., 2018). Once ballast is fouled, the ballast pressure decreases as the ballast layer settlement increases due to the breakage of ballast particles (Askarinejad, et al., 2018). This decrease in ballast pressure creates voids beneath the sleeper, as indicated in Figure 1. This leads to the movement of the sleeper and subsequently the loss of track geometry (Askarinejad, et al., 2018). Frohling, (1997), conducted ballast pressure tests along the Coal line in South Africa. The test indicated that the deflection of sleepers varied from 1mm to 6mm across the line, thus indicating areas of ballast settlement (Frohling, 1997).

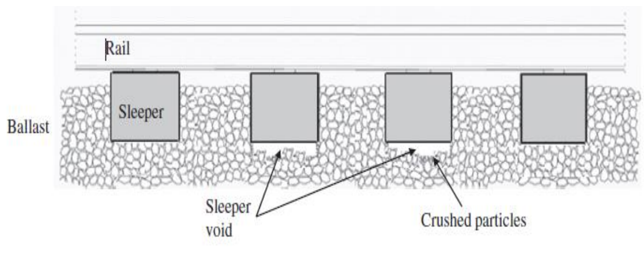

Figure 1. Diagram showing voids beneath the sleeper due to fouled ballast (Askarinejad, et al., 2018)

Fouled ballast enhances plastic deformation of the ballast layer which subsequently deteriorates the geometry of the track superstructure due to the decrease in the load bearing capacity of the ballast (Nimbalkar, et al., 2014). This is further indicated by the Triaxial test conducted by (Nimbalkar, et al., 2014) on the Coal line in Australia which indicates that degradation. However, the shear strength of the ballast is significantly reduced when there is an increase in fine particles in the ballast layer. Koohmishi & Palassi (2018) adds that the ballast layer's ability to provide drainage to the track structure is reduced by stating that "*Fouling leads to the reduction in the rate of percolation of water through the coarse aggregate layer due to filling the air voids with fine particles*". This was based on permeability tests conducted on fouled ballast and clean ballast which indicated that the permeability of fouled ballast was significantly reduced (Koohmishi & Palassi, 2018).

Ballast is a crucial component of the track structure, however ballast fouling compromises the stability of the track. As previously stated, ballast fouling increases the cost of maintenance, therefore alternative designs of the ballast layer should be considered in order to sustain the service life of the track to its potential life span in an economic manner without compromising the tracks stability (Indraratnaa, et al., 2017).

2.4 Ballast coated in Rubber

It is estimated that by the year 2030, 1200 million tyres will be discarded into stockpiles and landfills (Corinaldesi & Donnini, 2019). This poses a health risk to humans and the environment. Therefore, there is a need for innovative methods to utilize recycled tyres. Neoballast (Figure 2) are ballast stone that are coated with rubber particles (0,5mm) generated from recycled tyres with the aid of a binder (Sol-Sa´nchez, et al., 2018).

Figure 2. Ballast coated in rubber particles i.e. Neoballast (Valentí, et al., 2016)

Corinaldesi & Donnini (2019), states that in recent years there has been an increase in the use of recycled rubber tyres in many civil engineering projects with one of them being the railway industry. Tyres consist of 90% vulcanised rubber (Medina, et al., 2018). Medina, et al., (2018) stated that "*Vulcanised rubber is extremely durable, strong, flexible and can maintain its volume under loading, thus making it suitable to be used as aggregate for composites*". Therefore, suggesting that coating the ballast with recycled rubber tyres would make the ballast more durable. Valentí, et al., (2016) stated that the rubber coating increases the elasticity of the ballast as well as mitigates the rate of degradation of the ballast. Thus, coating the ballast with rubber aims to do the following:

1. Decrease the degradation of the ballast layer by providing a more durable aggregate.
   Corinaldesi & Donnini (2019) stated that the recycled rubber in aggregates act as crush barriers. This property may assist in decreasing the rate of ballast fouling in the ballast layer.
2. Reduce the frequency of ballast replenishment on the Coal line – which will in turn reduce the economic and environmental cost of ballast by reducing ballast fouling.
3. Reduce the degree of deflection of the track on the Coal line by reducing settlement.
4. Increase the energy dissipation due to the rubber particles surrounding the ballast stone and the viscosity of the rubber. Medina, et al., (2018) conducted a study that indicated that the vibration dampening coefficient of the aggregate increased with an increase in rubber content. Thus indicating that when recycled rubber tyres are used in aggregate it increases the impact energy dissipating capacity of the aggregate. The energy dissipating property of Neoballast was confirmed by the fatigue tests conducted by Sol-Sa´nchez, et al., (2018). It reduces the track stiffness by reducing the vertical deflection of the ballast layer (Valentí, et al., 2016). This property may be favourable to the ballast layer as one of the functions of the ballast is to transfer loads and reduce vibrations to the underlying formation layer (Indraratnaa, et al., 2017).
5. Reduce noise pollution- A study conducted by Corinaldesi & Donnini (2019) indicated that when the rubber content in aggregates are increased, the sound absorption property increases and hence reduces the noise.
6. Present the potential to increase the electric resistance of ballast aggregate. Corinaldesi & Donnini (2019) conducted a study which

indicated that an increase in rubber content increases the electric resistance of the aggregate. This may provide a safety feature in the ballast layer as the Coal line in South Africa runs live 25 kilovolt (kV) through its overhead track equipment through its entire line with the rails providing a medium for return current (Shawe & Kruger, 1987). However, this will not be the primary purpose of the Neoballast layer but rather a secondary function.

As mentioned above, coating the ballast aggregate with rubber particles may provide the ballast layer with advantageous mechanical properties. A static test conducted by Sol-Sa´nchez, et al., (2018) indicated that there is a decrease in long term settlement of Neoballast with the Settlement Ratio per Load Cycle being 2,8 x 10^{-6} mm/cycle compared to 8,1 x 10^{-6} mm for conventional ballast. However, Sol-Sa´nchez, et al., (2018) indicated that the Neoballast layer will have to undergo higher compaction upon installation as compared to the conventional ballast to avoid initial high settlement. These tests were conducted using a 20 axle ton load and a Neoballast layer thickness of 300mm. The results from the tests indicated that the use of Neoballast may decrease the settlement due to cyclic loading on Heavy Haul lines. Therefore, the frequency to conduct maintenance to correct track geometry will be reduced. The mechanical strength of the ballast layer is vital to the stability of the track (Ciotlaus & Kollo, 2018). Literature and past studies conducted on Neoballast in practice are limited.

2.5 *Ballast Specifications Currently on the Heavy Haul Line in South Africa*

On the Coal line in South Africa, ballast must comply with the South African Bureau of Standards (SABS) 1083 as well as the Specification 406 (S406) (Spoornet, 1998). Table 1 below indicates the grading of ballast that must be complied with:

Size of Sieve (mm)	% by mass passing
73,0	100
63,0	90-100
53,0	40-70
37,5	10-30
26,5	0-5
19,0	0-1
13,2	1

Table 1. Grading of Ballast on Heavy Haul lines in South Africa (Spoornet, 1998)

According to Spoornet (1998), the Los Angeles (LA) Abrasion tests shall not exceed 22% and the Mill Abrasion tests shall not exceed 7%. The results from the Water Absorption tests must not be more than 1% (Spoornet, 1998). Furthermore, there must not be more than 5% of mass loss after 20 cycles when the Soundness test is conducted (Spoornet, 1998). These are the specifications for Ballast used on the Heavy Haul line in South Africa.

3 METHODOLOGY

A Soundness test, LA Abrasion test, Mill Abrasion test and Water Absorption test was conducted on the ballast used on the Coal line in South Africa and on the Neoballast. A comparative analysis will then be applied to examine the results of these tests. This was done to test the viability of the Neoballast on the Heavy Haul lines in South Africa in accordance with the minimum requirements for ballast on the Coal line specified in the S406. The results for the tests of Neoballast was obtained from COMSA who have conducted these tests in Barcelona. The tests that were done on the ballast used on the Heavy Haul lines was conducted at the Transnet Laboratories. These test were conducted in accordance with the S406 (Spoornet, 1998). Tests done on the Coal line ballast as well as the Neoballast was conducted on ballast of similar grading and ballast material. The ballast utilized in the tests of the Neoballast and coal line ballast were of grading 37,5mm to 53mm. Quantities of aggregate used in each of the tests were kept constant for both the Coal line ballast and the Neoballast.

3.1 LA Abrasion Test

The ballast aggregate is subjected to dynamic loads and wear from the overlying sleepers (Indraratnaa, et al., 2017). The ballast layer must be strong enough to resist the loads applied to it that will result in degradation, crushing and disintegration of the ballast aggregate (Interactive, 2018). The LA abrasion test is used to test the ballast aggregates abrasion and toughness properties. The ballast aggregate that passes through the No.12 sieve size (1,70mm), is placed into a steel drum that contains 12 steel spherical balls. The rotating drum subjects the ballast to impact, grinding and abrasion. After the rotation has been completed, the ballast that is still retained on the No.12 sieve is weighed and a percentage of abrasion loss is calculated using Equation 1. This value indicates the toughness of the ballast aggregate.

$$LA\ Abrasion\ Loss = \left(\frac{M_{Original} - M_{Final}}{M_{Original}}\right) x\ 100 \qquad (1)$$

Where:

$M_{Original}$ = Mass retained on No.12 sieve before the test

M_{Final} = Mass retained on No.12 sieve after the test.

(Interactive, 2018)

3.2 Mill Abrasion Test

Similar to the above mentioned LA Abrasion test, the Mill Abrasion test measures the abrasion and toughness properties of the ballast aggregate (Interactive, 2018). The ballast particles must meet two requirements, as follows. One portion of ballast must pass through the 37,5 mm sieve and be retained on the 26,5 mm sieve whilst the second portion must pass through the 26,5 mm sieve and be retained on the 19mm sieve (Spoornet, 1998). The both portions of ballast are then placed in the Mill pot which rotates at 33 rotations per minute (r.p.m) for 10000 revolutions (Spoornet, 1998). The mass of the ballast that is retained on the 9,5mm sieve is weighed and the mass of ballast retained on the 0,075mm is weighed. The Mill Abrasion value is then calculated using Equation 2. The lower the Mill abrasion value is, the less prone the ballast aggregate is to degradation due to the loads subjected to it.

$$Mill\ Abrasion\ Vale = \left(\frac{M_{Original} - M_1 - M_2}{M_{Original}}\right) x\ 100 \qquad (2)$$

Where:

$M_{Original}$ = Mass passing through the 37,5mm sieve and retained on the 26,5 mm sieve plus the mass passing through the 26,5mm sieve and retained on the 19 mm sieve before the test.

M_1= Mass retained on the 9,5mm sieve after the test.

M_2= Mass retained on 0,075mm sieve after the test.

(Spoornet, 1998)

3.3 Sodium Sulphate Soundness Test

The ability of ballast to resist disintegration due to weathering and freeze-thaw cycles is determined by the Soundness test (Pavement Interactive, 2019). The durability of ballast determines its potential to be subjected to degradation and its potential to withstand extreme temperatures (Pavement Interactive, 2019). The more durable the aggregate is, the less prone it is to degradation due to weathering (Pavement Interactive, 2019). During the soundness test, the ballast aggregate that passes through the 19mm sieve and retained on the 13,2mm sieve, is submerged in Sodium Sulphate (Na_2SO_4) solution repeatedly (Spoornet, 1998). The portions of Na_2SO_4 solution that are submerged in the ballast pores forms crystals that subsequently creates internal forces within the aggregate, thus producing internal pressure on the pores of the aggregate which will result in the breakage of the ballast. (Pavement Interactive, 2019)

The durability of the ballast aggregate is measured by weighing the mass of the ballast before and after the test. This is done using Equation 3.

$$Soundness\ Test\ Loss\ = \left(\frac{M_{Original} - M_{Final}}{M_{Original}}\right) x\ 100$$

(3)

Where:

$M_{Original}$ = Mass passing through the 19mm sieve and retained on the 13,2 mm sieve before the test

M_{Final} = Mass retained on No.12 (1,70mm) sieve after the test.

(Pavement Interactive, 2019)

3.4 Water Absorption Test

Water absorption tests are done to measure the ballast aggregates capacity to retain water (PRBDV, n.d.). As the water absorption of the aggregate increases, the porosity of the aggregate increases (PRBDV, n.d.). This is done by using a perforated basket and submerging the ballast aggregate in water for over 24 hours (PRBDV, n.d.).

The weight of the ballast aggregate before and after the test is measured to calculate the density and water absorption property of the aggregate.

4 RESULTS AND ANALYSIS

4.1 Los Angeles (LA) Abrasion test

As seen from the results of the LA Abrasion test indicated in Figure 3, the Neoballast abrasion resistance is 96% more than the abrasion resistance of the current ballast used on the Coal line. This indicates that Neoballast has a higher abrasion resistance compared to the normal ballast. This result further indicates that the rubber coating on the Neoballast acts as a crush barrier which will in turn result in a reduction in fines produced and hence a reduction in ballast fouling (Corinaldesi & Donnini, 2019). A reduction in ballast fouling will result in a low ballast settlement rate per load cycle (Sol-Sa´nchez, et al., 2018). Furthermore, the degree of track deflection ('blind slacks') will be decreased. According to Transnet specifications for Heavy Haul lines, the percentage loss from the LA abrasion test should not exceed 22% (Spoornet, 1998). Thus, the results indicate that Neoballast would be suitable for Heavy Haul lines with respect to meeting the LA Abrasion parameter.

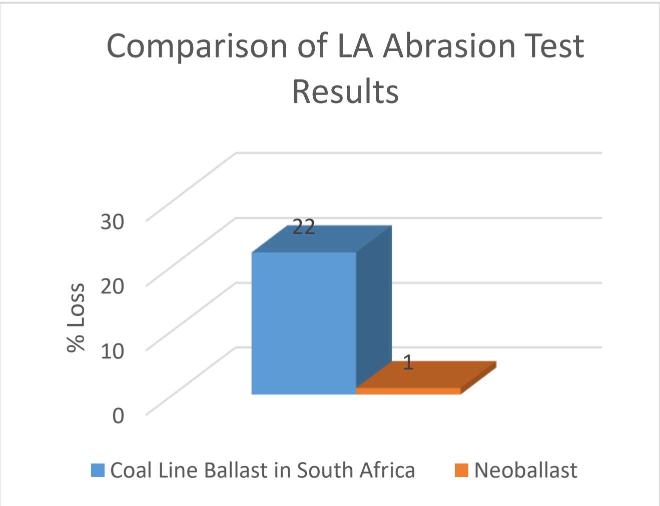

Figure 3: Results from LA Abrasion Tests

4.2 Mill Abrasion Test

As indicated by the results from the Mill Abrasion tests in Figure 4, the Neoballast provides 100% better resistance as compared to the ballast currently used on the Coal line. Results from the Mill Abrasion test combined with the results from the results of the LA Abrasion test indicate that the Neoballast is more durable and tough compared to the current ballast used on the Coal line. The test conducted on the Neoballast by Valentí, et al., (2016), indicated that after the test was conducted the Neoballast aggregated maintained its angularity. This indicates that the Neoballast will maintain its interlocking properties for a longer period of time, hence the shear strength capacity of the ballast layer will be optimized. This will reduce the economic cost of maintenance for the restoration of track geometry and fouled ballast. With respect to the standards provided by Transnet for Heavy Haul lines, the loss of mass from the Mill Abrasion test must not exceed 7% (Spoornet, 1998). Therefore, the Neoballast would be suitable for Heavy Haul lines in terms of the Mill Abrasion specification.

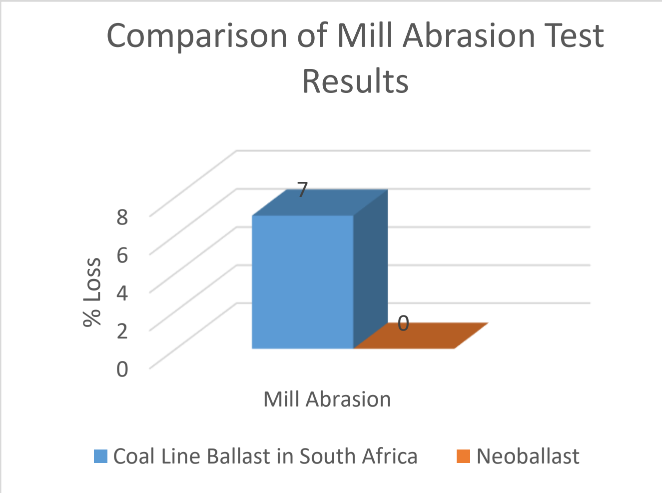

Figure 4: Results from Mill Abrasion Tests

4.3 Soundness Test

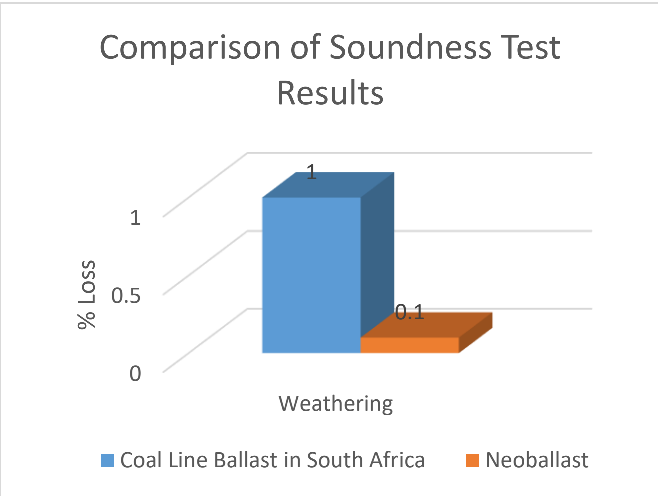

Figure 5: Results from Soundness Tests

The results from the soundness test in Figure 5 indicates that the Neoballast has a 90% improvement in the resistance to weathering as compared to the Coal line ballast. This indicates that the Neoballast would perform better than the current ballast used on the Coal line in extreme temperatures like that of the areas of the Heavy Haul lines in South Africa. According to Transnet's ballast standards for Heavy Haul lines, the loss of mass from the Soundness test must not exceed 5% (Spoornet, 1998). Since the loss of mass of Neoballast is 0,1%, it may be suitable for the Heavy Haul lines with respect to weathering.

4.4 Water Absorption Test

It is observed from Figure 6 that the current ballast on the coal line absorbs 75% more water than the Neoballast, thus indicating that the Neoballast is 75% less porous than the current ballast. Furthermore, this indicates that the Neoballast would be able to facilitate drainage more efficiently with less likelihood of contributing to the degradation of the ballast layer as compared to the current coal line ballast. In terms of specifications, the maximum allowable percentage of water absorption for the Heavy Haul line ballast is 1% (Spoornet, 1998). The water absorption percentage for the Neoballast was 0,25%. Therefore, the Neoballast would be suitable for the Coal line based on the required specifications.

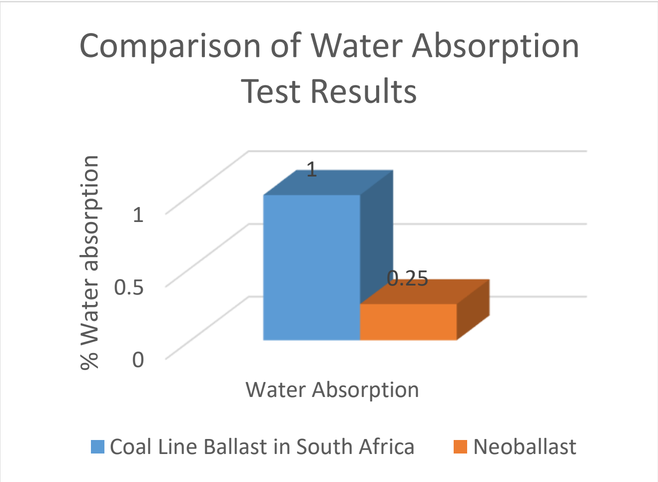

Figure 6: Results from the Water Absorption test

5 CONCLUSION

This study examined the viability of Neoballast on the Coal line in South Africa in terms of its mechanical properties and the minimum required specifications for Heavy Haul lines in South Africa. Tests were conducted on the Neoballast and the current ballast used on the Coal Line to test the abrasion resistance, durability, weathering resistance and the water absorption of both aggregates. A comparative analysis was done to establish which ballast is more suitable based on the results from the tests as well as the minimum required specifications provided in the S406. The results from the study indicated that the Neoballast present 96% more abrasion resistance from the LA Abrasion test and 100% more abrasion resistance from the Mill Abrasion test as compared to the current Coal line ballast. The soundness test indicated that Neoballast would perform better in extreme weather conditions as compared to the current Coal line ballast with Neoballast offering 90% more resistance to weathering. The water absorption test indicated that Neoballast will provide a better medium for drainage as it is 75% less porous than the current ballast. From the results it can be concluded that the use of Neoballast aggregate as the ballast layer is more durable and would result in a decrease in the degradation of ballast particles and a decrease in the rate of settlement per load cycle of the ballast layer. The Neoballast met all the minimum required specifications for ballast on the Heavy Haul lines in South Africa. Thus indicating that the Neoballast would be viable for use on the Coal line in terms of its mechanical properties. It can further be concluded that the Neoballast will reduce the rate of track geometry deterioration and in turn reduce the cost of maintenance on Heavy Haul lines.

6 FUTURE RESEARCH

The limitations of this research is that the Neoballast was not tested on a Heavy Haul line test track with applied cyclic loads of 26 axle tons. Future studies should test the mechanical properties of Neoballast on a railway track section representing the Coal line specifications of a UIC 60kg rail under a 26 ton axle load. Static and Dynamic load tests should also be conducted to investigate the settlement of the track. Future studies should also investigate the disposal methods of Neoballast and the environmental effect of Neoballast in practice.

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