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Durability Performance of Concrete Debris and Bottom Ash as an Alternative Track Ballast Material

D Youventharan^{1*}, P J Ramandhansyah¹, K M Jeevithan¹, O Rokiah², S Mohd Arif² and H Yaacob³

¹Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Malaysia

²Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Kuantan, Malaysia

³Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia

Corresponding author: youventharan@ump.edu.my

Abstract. Concrete debris and bottom ash has been identified as the potential materials to be used in construction industry. This would certainly reduce wastage produced from construction and demolition (C&D) activities and bottom ash from the power plant. However, the concrete debris waste and the bottom ash are been neither tested nor proven to be feasible in the construction of railway track. This paper will discuss the potential usage of concrete debris collected from destruction site and also the bottom ash waste from Coal Energy Power Plant. Currently, neither concrete debris nor bottom ash is used in railway construction. The main objective of this study is to analyse the engineering properties of bottom ash and concrete debris along with the conventional ballast to verify whether the traditional material can be replaced or otherwise. Experiments such as the sieve analysis test, Los Angeles abrasion test, aggregate impact value test and the aggregate crushing value test were conducted to measure the properties. The engineering properties tested in this research are the hardness, toughness and resistance towards impact and crushing of ballast. In terms of gradation, particle size distribution curve was plotted and compared in this research. It was found that the mixture of concrete debris and track ballast in the proportion of 50:50 each has brought some improvement to the properties and tend to behave close to the existing track ballast. The mixture of concrete debris and track ballast also shows that its crushing resistance is better than the existing track ballast. In conclusion, both the waste materials used in this research is highly potential to partially complement traditional material of track ballast.

1. Introduction

Over the last decade Malaysia has seen many advance changes especially in the mode of rail transportation. From monorail to the light rail transit (LRT) and mass rapid transit (MRT) in the beginning and now for the first time the high speed train (HST) connecting Malaysia and Singapore. Undoubtedly the railway projects in Malaysia are carried out simply to improve the quality of existing transportation system apart from to provide a conducive, safe and passenger-friendly train service.

¹ To whom any correspondence should be addressed.



This also includes giving more options and to improve the safety during operations as the technological related accidents are more common here than deaths due to natural disasters. According to the Ministry of Transport, Malaysia, millions of passengers are using the rail transport services as shows in table 1 and the numbers are ever increasing. In response to the demand, Malaysian government has planned to widen the rail transport network to the east-coast of Peninsular Malaysia. The biggest issue of all time when it comes to construction of railway track or any other construction projects are always been the cost and how sustainable it could be in the long run. Many efforts through research are being carried out to find out the most cost effective and the sustainable approach in construction. One of the efforts is by looking for alternative material that can either replace completely or partially the existing non-renewable ballast material which is obtained from the natural resources.

Table1: Number of passengers for rail transport service

Rail type/line	No of Passengers
Kelana Jaya line	87,216,597
Ampang line	60,960,445
MRT SBK line	51,314
KTMB	3,527,000
Commuter	32,078,000
ETS	3,933,000

Source: 2018 Transport Statistics Malaysia, Ministry of Transport Malaysia

Generally, ballast is a highly permeable granular material used as a load bearing material. Due to its relatively low cost of construction and less maintenance, ballasted track is still the most common and preferred railroad structure in most part of the world. Ballast is composed of medium to coarse gravel sized aggregates (10-60mm) with a small percentage of cobble-sized particles. Ballast with its good drainage properties are normally produced from natural deposits of granite, trap rock, quartzite, dolomite and limestone. Over usage of natural deposits may cause severe destruction to natural habitats and instable ecosystem when mountains and hills are destroyed for the building of railway tracks. Destruction of granite stones causes imbalance in the ecosystem and contribute heavily to global carbon footprint. Concrete debris is one of the major construction and demolition waste materials. In 2016, concrete waste in Kluang was approximately 20% of the total construction waste produced. Hence illegal dumping have becomes a normal site and this will cause a major environmental problem if no necessary steps are taken. Malaysia is aiming at zero waste at construction site by the year 2030. To achieve this vision, the Construction Industry Master Plans was implemented by the Construction Industry Development Board (CIDB) in Malaysia.

Moving on to other types of waste, about 40% of electricity in Malaysia is generated using combustion technique with pulverized coal. The utilization of pulverized coal produces by product known as Coal Bottom Ash (CBA). To date some of the key energy producing plants is located at Tanjung Bin in Johor, Kapar in Selangor, Manjung in Perak and Jimah in Negeri Sembilan. The Tanjung Bin power plant was started in September 2006 with the energy production capacity of 2100 MW. In record, this plant and others produce waste about 180 tonnes per plant daily and end up in ash ponds and landfills for years. As a consequence of this, there are always unresolved issues of land conservation and violation of regulations with the infrastructures built for this purpose and effects the environment due to the existence of ash ponds and landfill sites. This situation may get worsen as coal is being used due to its availability at cheaper price. When pulverized coal undergoes combustion in a boiler, about 80-90% of the residual material that is not burned or ash that is entrained in the flue gas is recovered as fly ash. Bottom ash is the remaining 10-20% of the ash which is dark grey, porous, granular sand sized material.

Bottom ash is classified as Schedule Waste (SW 104) under the Environmental Quality (Schedule Waste) Regulation 2005 of the Environmental Quality Act 1974. It is estimated that by the year 2020, the operational coal fired power capacity in Malaysia will be approximately 15,000MW and will generate 0.657 million tons of Bottom Ash (BA) per year which will be deposited into the ash pond. The nature of this agglomerated ash particles which is too big to be transported in the flare gases will normally fall through the open gates to an ash hopper at the bottom of the furnace. Generally bottom ash is extracted from various plants and factories after being cooled and conveyed using dry ash technology. Bottom ash is used in some countries to produce concrete and other useful materials such as replacing sand and aggregate for the road construction and cement powder production. Bottom ash has been clearly seen as an alternative material of choice for construction due to low cost of raw material and building concrete structure as well as saving the environment by reducing carbon footprint.

Usage of ballast in railway construction or maintaining railway track can be less economical in future when the demand of ballast increase and the natural resource decrease. Hence it may require replacement of natural ballast with other alternative material which has the same engineering and physical properties. Concrete debris from C&D and bottom ash has a huge potential engineering usage and efficacy in railway track construction. Hence it will be very insightful for the Department of Environment of Malaysia to stop encouraging the usage of natural resources like the traditional ballast for the construction and reduce its dependency when there is already an attractive waste material available at no cost.

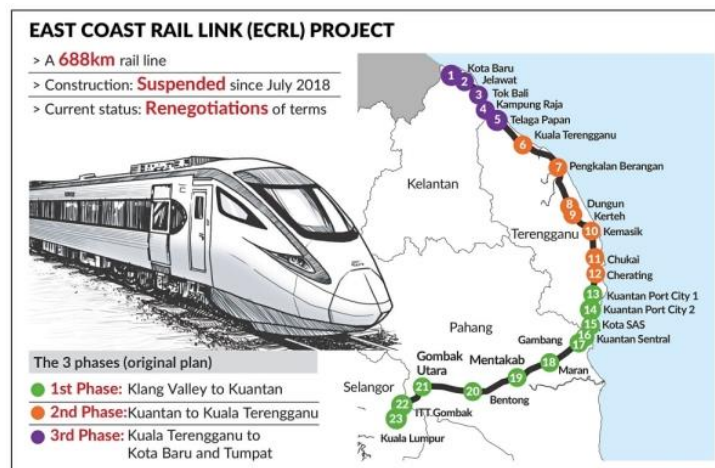


Figure 1. East Coat Rail Link Routes (Source: www.thestar.com.my)

2. LITERATURE REVIEW

2.1 Introduction on ballast Material in railway industry

All track components have a very vital role to reduce the wheel load and contact pressure gradually to successive reduced level from interface to interface which is from rail to sleepers and to ballast down to sub-ballast which is in-contact with the subgrade. The largest component of the track is the ballast layer which comprises a weight and volume of more than 1600 m³ to 2500 m³ tons for 1 km for a single track railway. The minimum specifications and cost are set by clients according to their satisfaction which is used to choose the source of ballast. The selected ballast material will be placed on the track subgrade functioning as a support to the track structure. The properties of conventional ballast are non-cohesive, coarse-sized, and a granular material with uniform gradation. The function of ballast is to provide support for the ties, provide resilience to absorb shock from dynamic loads, to drain water from track efficiently, maintain surfacing and lining operation, limit tie movements by forces acting vertically, laterally and longitudinally and to reduce stresses from loads of trains which might cause settlement. Well known for its strength and stiffness behaviour, Granite stone is still widely used as preferable materials in railway track. Granite is obtained via mining. Mining can cause

erosion, contamination of soil, groundwater and surface water because of chemicals sinkholes and loss of biodiversity. Granite is a non-renewable resource. Although the effects of mining towards the environment such as surface water, ground water, air, vegetation, fauna and population are insignificant and natural resources is a continuous process, over usage or rapid usage might cause absence of resources after a period. The prerequisites to minimize the maintenance cost are the suitable test and proper understanding of ballast properties. Track ballast will be serviced by complete replacement of stones once every three years mostly. Hence it is better to be ahead and find a better replacement material for the track ballast.

2.2 Construction waste in Malaysia

Malaysia is overflowing with waste and we are running out of options to store and discard them. Malaysia generates some 26,000 tons of C&D waste which is stuffing the already over-flowing landfills [1]. We Malaysians have less awareness in managing C&D waste properly [2]. Consequently, it has increased the illegal dumping sites that lead to environment problems to the communities [3]. CIDB has written a guideline to help partners in the construction business to comprehend the idea of waste minimization and integrated waste management and also help to move towards sustainable development practise and distinguish measures that can be embraced in their projects towards waste limitation. In the total waste generation, 28% are industrial and construction waste. According to the solid waste management hierarchy, waste minimization is the first step followed by reuse, recycle and waste treatment and final solution which might not be a good way is disposing to landfills. In construction waste management, reuse is making use of a material without alteration of its form. To avoid illegal dumping by the main contractor at Kuala Lumpur, all construction projects requires approval from the Kuala Lumpur City Hall council [4]. The solid waste and public cleansing management corporation (SWCorp Malaysia) plays an important role to ensure that the main contractors adhere and abide to the Act 627.

2.3 Previous Results on Concrete Debris

Studies conducted previously show there is an increase in compressive strength when concrete debris is substituted with aggregate in concrete mixture. Strength increases as the percentage of debris increased up to 15% and reached the maximum strength [5]. The tensile strength too increases gradually up to 10% compared to the conventional concrete when debris is added gradually from zero up to 10% by replacement and reduction technique. When there is an increase in compressive strength of concrete using waste materials from C&D, the flexural strength and split tensile strength also increase with high correlation value [6]. Whereas the correlation value between compressive strength and the non-destructive test (NDT) which is the pulse velocity and the Schmidt hammer test results were lower. It was recommended that the mixture of cement to concrete debris is in the ratio of 1:3 using crushed concrete debris. Hence a considerable slump and penetration is achieved and within the acceptable mobility like the standard mortar mixture [7].

2.4 Previous Results on Bottom Ash

Research shows that bottom ash can be used as aggregate replacement in various quantities to produce light weight concrete and autoclaved aerated concrete [8]. Bottom ash also can be used in producing geo-polymer mortar where kaolin raw material can be replaced either partially or fully during geo-polymerization process. Some projects have successfully used bottom ash along with fly ash to construct embankments at road side. According to a research finding, usage of bottom ash in concrete mixture did not result in any long-term detrimental effect to environment [9]. Even though this finding can be debateable when it comes to environment issue, continues assessment on the feasibility of these materials needs to be carried out. Studies on bottom ash to replace fine aggregates in making high bulk volume apart from fly ash in concrete carried out too. Bulk volume of pounded bottom ash was 4.75% more than sand because the gaps between the materials are filled up resulting in better density. Results also show that crushing of bottom ash into finer particle size will reduce the water absorption properties. When coarse and fine bottom ash was fully utilized in concrete mixture the compressive strength reached 75% as compared to the controlled sample. The engineering properties of bottom ash

from Tanjung Bin power plant is quite similar to the engineering properties of sand which means it is highly potential to be used in geotechnical applications [10]. It was suggested that bottom ash is used as the filling materials in civil and infrastructure work after the chemical properties are evaluated. Generally bottom ash is used in non-structural materials and cement treatment. The bottom ash with high organic content is not suitable to be used as building materials. The properties of bottom ash depend on the origin of the combustion plant.

2.5 Gradation

It seems that smaller sized ballast ($\leq 20\text{mm}$) was more preferable in the past because it is easy and efficient for the maintenance of track by manual means [11]. New ballast can be considered to fit the category of “uniformly-graded ($C_u < 4$). Fouled ballast is termed as gap-graded material which has small amount of particles in a given size range compared to the total range of sized. Strength is not affected because of changes in gradation for common void ratios. But, increasing the particle size range with the same mean size by broadening with the same mean size should increase the shear strength due to the decrease in void ratio which will exist with a broader grading.

The contamination of degree of fouling of ballast can be represented by the gradation curve that will be equal or greater than the percentage fines. When particle size increases, the strength did not change when compared to common void ratio. But, if the size increases, the breakage will also increase. In some available results, it shows that an increase, in some cases a decrease and there is no effect in some cases when particle size increased. The replacement of small amounts ($< 15\%$) of large particles size in ballast with smaller particle size increases the friction angle. The increase in the ballast aggregate size leads to reduction in point load strength.

2.6 Durability

Durability of track ballast can be investigated by testing the mechanical and functional properties. The test methods are; Los Angeles (LA) abrasion, Micro-Deval (MD) abrasion, point load, Freeze-thaw and triaxial loading test. The Los Angeles (LA) abrasion is the test on the impact and abrasion according to Norwegian specifications of railway ballast. Ballast condition can influence the condition of railway track and the durability of the remaining elements. Cyclic magnesium sulphate soundness test with Los Angeles abrasion tests will be useful to evaluate the suitability of ballast aggregates for the region with extremely cold temperature. The Micro-Deval (MD) abrasion test is used to know the minimum durability of the ballast life related to the surrounding climate and the type of sleeper. In North America, Mill Abrasion (MA) test is used to test durability even though it does not have a standard ASTM test procedures.

Durability of ballast is only tested in heuristic technique till date. The use of recycled aggregate from construction waste is detrimental to the quality of hardened concrete in terms of durability. Natural Vibration mode plays a vital role in deterioration of ballast layer [12]. The vibration of ballast causes ballast settlement and the change of track geometries, therefore influence track maintenance costs. However it is difficult to analyse the vibration of ballast because of its granular configuration and special mechanism of action. When the ballast material is less durable, breakage will happen.

2.7 Breakage Index

An investigation of railroad ballast particle breakages reveals that consideration taken into the calculation of time intervals between ballast screenings such as manually occurred breakage because of tamping, deterioration caused by the substructure or superstructure defect [13]. Dry abrasion test is not preferred because it produces less breakage effect compared to wet abrasion. The contact point of particles and the grain size has an inverse relation. When the grain size increase the contact point between particles will be large causing the force transferred will be high that could result in breakage as a result of inter-particle surface abrasion. The breakage index can be determined by dynamic pulsating laboratory experiment and Power Spectral Density diagram plots. The ballast Breakage Index parameters can be calculated and assessed by referring to changes in particle size distribution (PSD) curve. Generally to simulate the actual loading impact, about 225kN axle loads is taken for freight trains and 180kN for passenger train. Settlement is usually reduced with geo-grid installation

which has a better reinforcement provided by smaller embedment depth [14]. The ballast which is in direct exposure to the geo-grid will affect the overall settlement reduction because of a pressed-down or pushed through scenario which is caused by poor ballast size selection relative to the geo-grid aperture. Due to breakage, more fines will be produced hence the ballast breakage can be a reason for ballast fouling.

2.8 Fouling

Ballast can be progressively fouled by numerous fine materials as it ages. A large scale cyclic triaxial test can be used to observe the amount of plastic deformation that has direct connection with fouling. This will decrease the shear strength with the reduction in resiliency and drainage capability of ballast. The interlocking between the adjacent angular particles decreases when ballast fouling happens due to the presence of silt and clay materials [15]. Degradation of particles is the prime reason for ballast fouling. Void Contaminant Index (VCI) captures the fouling of ballast and shows more realistic fouling index when the specific gravity of fouling materials is different from the rock aggregates. Degradation of particles is the prime reason for ballast fouling. Single particle breakage of asperities leads to degradation of ballast. These phenomena can be tested by point load test on single ballast and impact loading test on packed ballast [16]. With Crumb rubber, the first stage or the first 1000 turns in an abrasion test can be protected, especially the easy lost part. But when the effect is long term, which can be indicated by a 2000 turn in abrasion machine is not satisfactory [17]. Highly angular ballast is capable to accommodate fouling [18]. Fouling of ballast can cause settlement and affect the drainage on the track.

2.9 Drainage

The movement of water through ballast and sub ballast for single-Line railway track can take up-to 4 days [19]. The causes of drainage failures are upward groundwater flow, precipitation on the surface of the track and collected surface flow from the surrounding area. The draining stream should not be blocked for the free lateral drainage to occur from the ballast and sub-ballast. Fouling can affect the drainage property of the entire structure. Another problem that damages the ballast structure is the drainage problem caused by accumulation of water in one side of the track and between tracks. The drainage potential of the track increases depend on the ballast course which is one of the most important structural layers of a railway track. Inadequate ballast drainage can cause problems such as ballast pockets, granular layers pollution, track collapse and detriment of upper layer. The hydraulic conductivity of ballast will decrease because of the infiltration of external fouling materials, intrusion of fine particles from subgrade and degradation of aggregate which makes further water remains in the granular layer of the track structure. Sand contaminated ballast can influence the condition of water flow by porous media and the capacity of drainage.

3 Methodology

The controlled sample of track ballast was collected directly from the existing railway track at Taiping, Perak KTMB railway station. The engineering properties of the ballast were tested in order to classify and identify the properties of the material. Concrete debris sample was taken from two different places, one from a construction and demolition site of a 30 years old building at Kuala Lumpur. Another sample was taken from the waste dump bin of concrete laboratory of Universiti Malaysia Pahang. The bottom ash sample was collected from Tanjung Bin plant, Johor. Initially the track ballast and the concrete debris samples were washed to remove dirt from the aggregates in order to avoid any inconsistency in results. After that both the materials were placed in oven for 24 hours and dried at 110 °C. Another set of ballast were crushed into 10mm size using the aggregate crushing machine for aggregate impact value (AIV) and aggregate crushing value (ACV) tests. The original track ballast was tested using sieve analysis test, Los Angeles abrasion test, aggregate crushing value (ACV) test and aggregate impact value (AIV) test. Ballast was mixed in different proportion with other materials as shown in table 2. All the mixed samples were tested using the same experiments as the controlled sample. Finally all the result was tabulated in tables and graphs in order to analyse the

durability performance. The laboratory test was carried out at the Highway and Traffic laboratory and Soil and Geotechnical laboratory of Universiti Malaysia Pahang, Gambang.

Table 2: Experimental design mix of track support mixture

Sample Mixture	Track Ballast (kg)	Bottom Ash (kg)	Concrete Debris (kg)
A	1.0	0.0	0.0
B	0.0	0.0	1.0
C	0.5	0.0	0.5
D	0.5	0.25	0.25
E	0.5	0.5	0.0

4 Results and Discussions

4.1 Sieve analysis

From the sieve analysis test, it shows that the gradation curve of existing track ballast is located to the left from the curve of concrete debris taken from demolition and laboratory activities. Figure 2 clearly shows that the distribution of particle size of concrete debris is close enough to the ballast requirement compared to the existing track ballast. However, the gradation curve of track ballast did not fit in to the upper and lower limit set by the American Railway Engineering and Maintenance-of-Way Association (AREMA). This might be because of ballast having gone through a series of damages and fouling effects after being used in the track. The particle size distribution curve of bottom ash is located away from the standard ballast boundary limits and other materials because of its average particle size and fouling index of 54.193 which falls into the category of highly fouled (>40). This could serve as a new indicator as how an alternative material would behave when used in addition to the conventional ballast material.

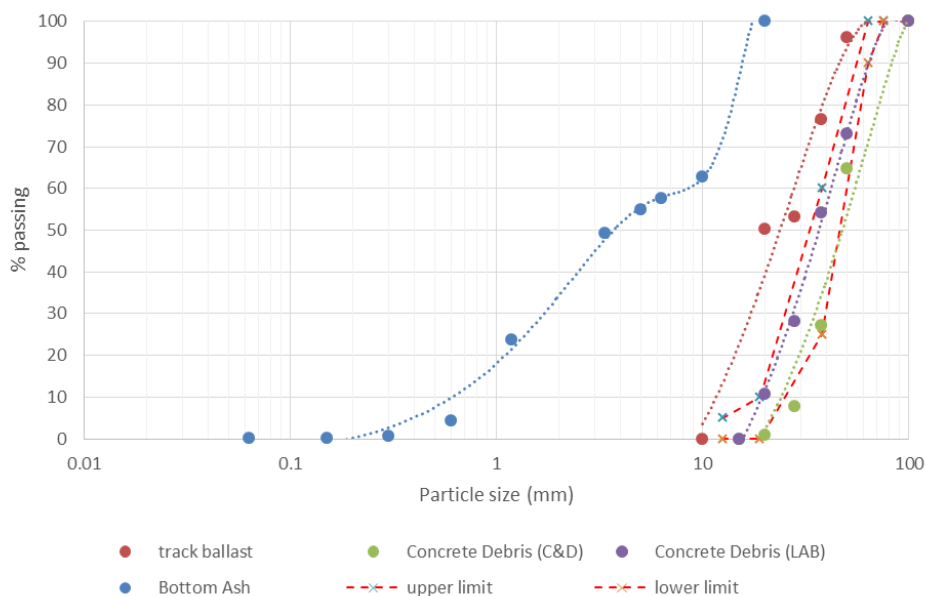


Figure 2. Particle size distribution curve and boundary limits of AREMA

4.2 Aggregate Abrasion Value

Based on Figure 3, the nearest percentage of loss compared to the controlled sample is C&D concrete debris followed by concrete debris from laboratory. The bottom ash shows the highest loss percentage.

Los Angeles abrasion test was conducted on aggregates to measure the abrasion resistance which includes degradation, disintegration and crushing of an aggregate. When ballast was tested twice it shows a range of percentage loss in between 11.8% and 14.0% respectively. Concrete debris from an old building shows a loss of 30%. Whereas, the concrete debris from the laboratory was 49% and this could be due to the design mix factor of concrete. The bottom ash sample recorded the highest loss of 80.4% after 500 swings simply because of the original average size of the material is not in the range of aggregate and not suitable to be tested using LA abrasion test. Therefore, the nearest percentage of loss compared to the controlled sample is C&D concrete debris followed by concrete debris from laboratory. However only concrete debris obtained from old building fulfilled the standard requirement of AREMA which is not more than 35%. This indicates that the alternative materials would not be advisable to be used in its original state. There must be a mix and match amount to reduce the abrasion and to avoid degradation when applied on site. Even though the bottom ash is highly degradable and not within the standard requirement, there is a high change of changing the durability of existing ballast and sub-ballast when used as partial filler. This behaviour was observed when bottom ash was partially used in design mix in the following tests mentioned in section 4.3 and 4.4.

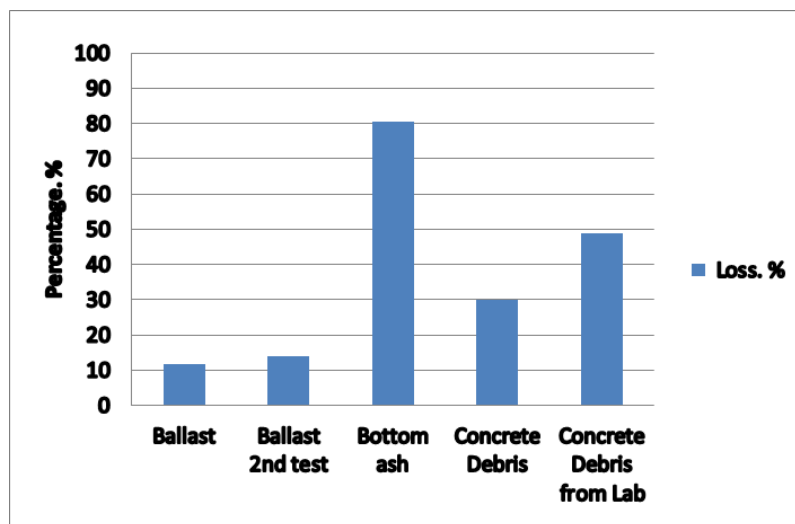


Figure 3. Sample types versus percentage of losses in LA abrasion test.

4.3 Aggregate Crushing Value

Next, experiments on design mix were carried out to determine the resistance towards crushing under compressive load which is applied gradually according to BS 812, Part 112:1990. Based on Figure 4 it shows that sample A (ballast without alternative material) recorded loss of 31.68% which is within the allowable limit of 35% fixed by AREMA. Sample B (concrete debris only) shows a loss of 38.562%. However when the ballast was mixed with concrete debris (sample C) the loss was reduced to almost half. Adding bottom ash in the mixture (sample D) resulted in performance almost similar to sample A. Therefore, it is important to find out the right compositions of all these materials to bring down the loss during application. Otherwise the loss in the mixture could exceed the limit as in sample E when large amount of bottom ash was used along with ballast in test. Hence the mixture of ballast, concrete debris and bottom ash has the resistance towards crushing impact if not almost similar but better than using only the existing track ballast.

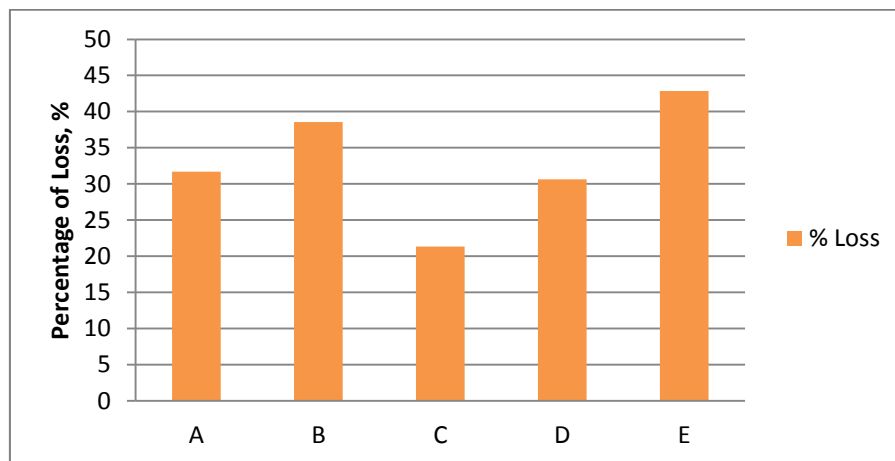


Figure 4. Aggregate Crushing Value of sample mixture

4.4 Aggregate Impact Value

Similar trend in ACV was observed when the sample design mix was tested to measure the resistance of the material towards impact or sudden shock. In other words, this time it was tested to know the toughness of a material according to BS 812, Part 112:1990. The AREMA guideline suggests that the impact value of aggregate shall not exceed 35%. As shown Figure 5, only sample A (ballast without alternative material) and C (ballast mixed with concrete debris) fulfilled the ballast application requirement. Even though other design mix was beyond the expected range there is a significant result to show how sample B and sample D have similar performance regardless of its different composition. This is again indicates how the bottom ash can reduce the performance of ballast and concrete debris in mix design. Sample E on the other hand show the limitation of bottom ash if not controlled in the mix design. Both the concrete debris and the bottom ash must be used in the right portion of ballast application to avoid under performance. For example adding half of sample A with bottom ash can reduce the performance of ballast. Whereas adding half of sample A with concrete debris could double the impact value of ballast when applied on site.

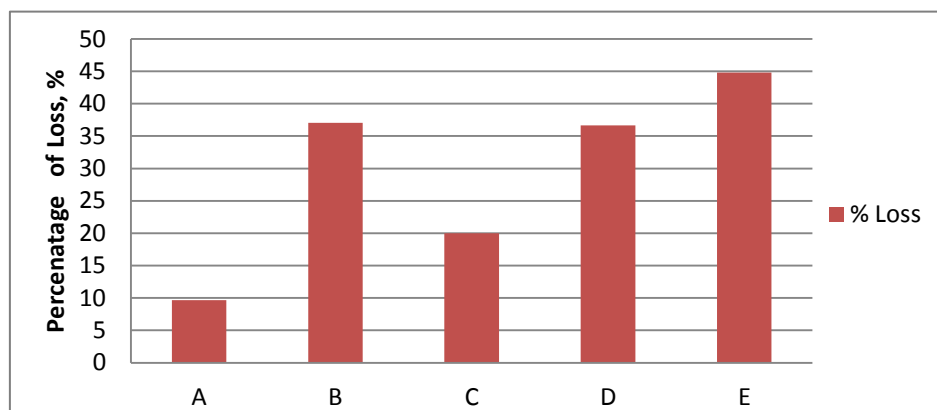


Figure 5. Aggregate impact value of sample mixture

5 Conclusions

There is a positive sign of improvement seen when two waste materials are added with the ballast. On the other hand adding just the bottom ash brings no impact to the durability of ballast. However this could be tested if feasible when bottom ash is used as one of the component of sub-ballast material. This research also finds out that, adding more concrete debris and less bottom ash in the ballast material certainly has high durability performance. However these findings could be more significant if only less ballast was used in the testing. Therefore, it is suggested that future testing are to be carried

out using less natural resources like the conventional ballast materials. Apart from that the mixture of concrete debris and bottom ash in track ballast is recommended to be tested further for other engineering properties too. Even though the concrete debris from the C&D has a potential to be used as track ballast, there are more issues and reliability concern when it comes to control the material selection in terms of strength and gradation. Similarly, the quality of bottom ash and the effects to the environment too needs further detail study before it can be fully applied on-site.

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