



Assessment of Indian Railways Track Ballast in the Regime of Semi High Speed & Heavy Axle Load Requirement

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Synopsis

The global urban population is increasing with a very fast rate which requires the resources and services to be increased in the same proportion. The transport service sector is a very important factor driving the economic development of any country. The rail transportation is most preferred & economical means for large as well as short distance due to its higher safety and comfort. Ballast is one of the five components of railway track on which a large part of railway budget is spent for maintenance. A good ballast provides resilience and drainage to the track therefore to maintain the desired gradation and strength ballast replacement is done after a certain time interval or after the passage of certain volume of traffic. The Indian Railways is using a subjective approach regarding the replacement, specifications and characteristics of ballast which are continuing from centuries. In this paper an assessment of the railway track ballast and comparison of the specifications of the ballast over the world railways with the practices followed in Indian Railways. Based on the review some recommendations regarding gradation, renewal criteria and specifications have also been suggested.

Keywords : Rail track, ballast gradation, fouling, abrasion, deep screening, Mill test.

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1. Introduction

Ballast is a selected crushed and graded aggregate material which is placed upon the railroad roadbed for the purpose of providing drainage, stability, flexibility, uniform support for the rail and ties and distribution of the track loadings to the subgrade and facilitating maintenance. There are distinct differences in the mineral composition of the various aggregate materials used for roadway ballast applications and the respective in track performance of those materials. Likewise, many variations exist in the mineral properties of aggregate materials within the same general nomenclature of the aggregates known as granites, traprocks, quartzites, dolomites, and limestones. One particular aggregate material may possess most of the desirable characteristics for a good ballast material while a deposit of apparently similar material located in the same general geographical area will not meet the applicable specification requirements for railroad ballast.

As per the National Transport Development Policy Committee Report 2013, the total length of Indian Railways network is increased from 53,596 km in 1950-51 to 64460 km in 2010-11 which is approximately 20.27% rise whereas on the other hand the road route km increased from 400 km in 50-57 to 4690 km in 10-11 which is a tremendous rise of approximately 1072%. The main reason for the drastic difference between the growth rate of railways route km and roadways route km can be the slower rate of construction of railway track whereas the rate of road construction is maintained as per the targets set by different road plans fixed from time to time.

Table 1: Growth of Railways and Roadways [11]

| Items | Unit | 1950-51 | 1960-61 | 1970-71 | 1980-81 | 1990-91 | 2000-01 | 2010-11 | % Increase |
|---------------------|---------|---------|---------|---------|---------|---------|---------|---------|------------|
| Rail (Route Length) | Km | 53,596 | 56,247 | 59,790 | 61,240 | 62,367 | 63,028 | 64,460 | 20.27 |
| Road | x1000km | 400 | 525 | 915 | 1485 | 2350 | 3373 | 4690 | 1072 |



The Indian railway is one of the largest of its kind in the world. Derailment of trains is a routine incidence & a major disaster in railways happens due to the change in alignment of rails and many other reasons. The substructure component ballast bed plays very important role in maintaining the standard gauge and hence alignment of the rails. Any defect or deficiency in the ballast layer leads to the settlement & deformation of ballast which finally results into geometric parameters deterioration. Railway ballast is uniformly-graded coarse aggregate produced from crushing (Machine or hand crushed) locally available rocks such as granite, basalt, limestone, slag or gravel.

The efficiency of track foundation material specially ballast decreases gradually due to insufficient lateral confinement, ballast breakage, ballast fouling & loss of shear strength of soil due to localized liquefaction & clay pumping. Ballast contamination or the filling of voids due to ballast breakdown and infiltration of other materials from the ballast surface or infiltration from the base of the ballast layer is known as ballast fouling. The fouling materials may be from surroundings, slurried (Pumped) formation soil (Soft clays & silts liquefied under saturated conditions) and coal from freight trains as well as ballast degradation (fine particles then migrating downwards). Railways spend a very high amount on the maintenance of ballast in the railway tracks [Table 2].

Table 2: Expenditure on Ballast per year (in Crore Rupees)

| Description | Maintenance | Construction |
|--|-----------------|--------------|
| | 2015-16 | 2015-16 |
| Track kilometers (in kms) | 1,15,000 | 1600 |
| Renewal Required (in kms) | 11,500 | 1600 |
| Ballast Required (in x 1000 m ³) (for maint. 1500m ³ /kms & for new lines 2250m ³ /kms) | 17250 | 3600 |
| Expenditure in (Crores Rs.) | 2691 | 561.6 |
| Total Exp. in 2015-16 | 3252.6 | |
| Tentative Exp. in 2016-17 | 3711.24 | |
| Tentative Exp. in 2017-18 | 4405.284 | |



The high expenditure on the track ballast must be controlled and a major portion of rail budget in lieu of can be utilized in other maintenance activities and renewal operations, this require a scientific approach to be followed with modern technology similar to other countries which are using modern techniques like ground penetrating radar (GPR) to evaluate the quality of ballast in track [2].

This paper presents an overview of ballast gradation & specification in Indian railways. It also highlights a comparison of Indian railways ballast specifications like gradation, abrasion test, service life with world railway practices.

2. Functions of Ballast

When selecting ballast materials it is necessary to define the type of material and the physical & chemical properties which can be measured in the laboratory by specific test methods. It is also most important to consider the field performance and behavioral characteristics of the ballast material in the railway track. Some of the properties which affect the field performance of ballast materials can be related to the crushing characteristics, hardness, durability, weight and other physical and chemical properties which are defined in the specifications.

High standards must be established for railway track ballast to provide a quality track structure. Likewise, ballast required for concrete tie installations must exhibit some different behavioral and performance characteristics than those ballast materials which will provide satisfactory field performance for wooden tie installations. Ballast is an integral part of the track structure. The ballast section must react to track loadings in combination with the superstructure and sub-ballast to provide supporting strength for the track and roadbed commensurate with specific railroad loadings and operating requirements.

This selected crushed material has several different functions which contribute to the service life and the performance of the railway



track. Robnett et al. (1975) and Selig and Waters (1994) discussed the functions of the ballast layer, of which the most important are listed below:

- a) Keeping the track in its required position by withstanding the vertical, lateral and longitudinal forces applied to the sleepers,
- b) Providing the required degree of elasticity and dynamic resilience for the track superstructure,
- c) Distributing stresses from the sleeper bearing area in order to achieve acceptable stress levels on the underlying material,
- d) Facilitating maintenance, surfacing and lining operations through the possibility of rearranging ballast particles by tamping,
- e) Providing immediate drainage for water falling onto the track,
- f) Providing sufficient voids for the storage of fouling material in the ballast and for accommodating the movement of particles through the ballast.

The ballast is required to perform these tasks without exceeding permissible limits of degradation brought about by the load and the environment to which it is exposed. It must also resist the entry of fine particles from the outside and thus ensure acceptable maintenance and renewal cycles. Experience has shown that good-quality crushed rock of volcanic origin satisfies most of these requirements when properly installed and compacted in the field.

The mechanical degradation of ballast grains produces fine particles of varying sizes. The volume of voids in a ballast layer on newly-constructed track is around 45 percent. When the railway track settles under heavy cyclic train loads, the ballast grains become more closely packed, hence volume of voids reduces. At this stage, primary ballast crushing occurs at the contact points between coarser grains. The corners and sharp edges break off and deposit in the voids between the grains. This permits further grain rearrangement, followed by additional ballast crushing upon traffic loading. The sliding and/or rolling action of the grains over each



other caused degradation of the aggregates through attrition. The outcome of this type of degradation is pulverized ballast particles which contribute to the fouling of ballast voids.

3. Indian Railways Ballast Specification

IR uses the ballast having the specifications given in the IRS-GE-1 code issued by RDSO in June 2004 with the latest correction slip issued in 2014. The various desirable properties of the railway track ballast as per this code are as follows.

3.1 Size and Gradation: The % finer on each sieve are described in Table 3 below.

Table 3: Gradation of Indian Railway Ballast

| Sieve Size (mm) | Preferred Limits | | Accepted Limits (with penalty) | |
|-----------------|------------------|-------------|--------------------------------|-------------|
| | Upper Limit | Lower Limit | Upper Limit | Lower Limit |
| 65 | 100 | 95 | 100 | 90 |
| 40 | 60 | 40 | 70 | 40 |
| 20 | 2 | 0 | 2 | 0 |

3.2 Physical Properties: The physical properties of the Indian railways ballast and the method for the determination of the different index/values is given in Table 4 below.

Table 4: Physical Properties of Indian Railways Ballast [9]

| Property | Limiting Values | Reference |
|--------------------------|-------------------------|-------------------------|
| Aggregate Abrasion Value | 30% Max | IS 2386: Part IV :1963 |
| Aggregate Impact Value | 20 % Max | IS 2386: Part IV: 1963 |
| Water Absorption | 1% (2.5% with approval) | IS 2386: Part III :1963 |



3.3 General Properties

a) Basic Quality: The ballast to be used in track should be hard, durable and as far as possible angular along edges/corners, free from weathered portions of parent rock, organic impurities and inorganic residues.

b) Particle shape: The ballast should be cubical in shape as far as possible. Individual pieces should not be flaky and should have generally flat faces with not more than two rounded/sub rounded faces.

c) Mode of Manufacturing: The ballast to be used in track may either be obtained after Machine crushing or Hand crushing. The Machine crushed ballast is always preferable in all the routes except class E-Route because class E-Route is having very small traffic load & it will not be a wise decision to use the Machine crushed ballast at these routes. On the other side Hand crushed ballast may be used only in Meter gauge, Narrow gauge and Broad gauge class E-Route because of the inferior quality of ballast as compared to Machine crushed ballast.

4. American Railway Engineering Maintenance-of-Way Association Ballast Specification

These specifications (American Railway Engineering Maintenance-of-Way Association (AREMA 2010) Volume-I, Part-2) cover the types, characteristics, property requirements and manufacture of mineral aggregates for processed (prepared) ballast. Ideally processed ballast should be hard, dense, of an angular particle structure providing sharp corners and cubical fragments and free of deleterious materials. Ballast materials should provide high resistance to temperature changes, chemical attack, have high electrical resistance, low absorption properties and be free of cementing characteristics. Materials should have sufficient unit weight (measured in pounds per cubic foot) and have a limited amount of flat and elongated particles.



4.1 Size and Gradation: The gradation of a ballast material is a prime consideration for the on track performance of ballast materials. The gradation must provide the means to develop the compact structure or density requirements for the ballast section and provide necessary void space to allow proper run off of ground water. Ballast gradations should be graded uniformly from the top limit to the lower limit to provide proper density, uniform support, and elasticity and to reduce deformation of the ballast section from repeated track loadings.

Table 5 outlines the recommended gradations to which the materials are to be processed for use as track and yard ballast. The grading of the processed ballast shall be determined with laboratory sieves having square openings conforming to ASTM specification E 11.

| Size No. (See Note 1) | Nominal Size Square Opening | Percent Passing | | | | | | | | | |
|--|--------------------------------|-----------------|--------|--------|--------|--------|-------|-------|------|-------|-------|
| | | 3" | 2.5" | 2" | 1.5" | 1" | ¾" | ½" | d" | No. 4 | No. 8 |
| 24 | 2.5"-3/4" | 100 | 90-100 | | 25-60 | | 0-10 | 0-5 | - | - | - |
| 25 | 2.5"-d" | 100 | 80-100 | 60-85 | 50-70 | 25-50 | - | 5-20 | 0-10 | 0-3 | - |
| 3 | 2"-1" | - | 100 | 95-100 | 35-70 | 0-15 | - | 0-5 | - | - | - |
| 4A | 2"-3/4" | - | 100 | 90-100 | 60-90 | 10-35 | 0-10 | - | 0-3 | - | - |
| 4 | 1.5"-3/4" | - | - | 100 | 90-100 | 20-55 | 0-15 | - | 0-5 | - | - |
| 5 | 1"-d" | - | - | - | 100 | 90-100 | 40-75 | 15-35 | 0-15 | 0-5 | - |
| 57 | 1"- No. 4 | - | - | - | 100 | 95-100 | - | 25-60 | - | 0-10 | 0-5 |
| Note 1: Gradation Numbers 24, 25, 3, 4A and 4 are main line ballast material. Gradation Numbers 5 and 57 are yard ballast material. | | | | | | | | | | | |

4.2 Physical Properties of Railway Ballast- The methods of sampling and testing as defined by this specification are in effect from April 1985 and may be revised or altered by the individual railway company. Field samples shall be secured in accordance with the current ASTM Methods of Sampling, designation D 75. Test



samples shall be reduced from field samples by the means of ASTM C 702. The different physical properties specifications are mentioned in Table 6 below.

Table 6: Physical Properties of Railway Ballast [1]

| Property | Ballast Material | | | | | | | |
|------------------------------------|------------------|----------|-----------|------------|---------------------|--------------------|--------------------|------------|
| | Granite | Traprock | Quartzite | Lime-stone | Dolomitic Limestone | Blast Furnace Slag | Steel Furnace Slag | ASTM Test |
| % material passing No. 200 sieve % | 1 | 1 | 1 | 1 | 1 | 1 | 1 | C 117 |
| Bulk specific gravity | 2.6 | 2.6 | 2.6 | 2.6 | 2.65 | 2.30 | 2.90 | C 127 |
| Absorption % | 1 | 1 | 1 | 2 | 2 | 5 | 2 | C 127 |
| Clay lumps and friable particles % | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | C 142 |
| Degradation % | 35 | 25 | 30 | 30 | 30 | 340 | 30 | See Note a |
| Soundness (sulfate) 5 cycles % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | C 88 |
| Flat and/or elongation particles % | 5 | 5 | 5 | 5 | 5 | 5 | 5 | D 4791 |

Note:

- Materials having gradations containing particles retained on the 1 inch sieve shall be tested by ASTM C 535. Materials having gradations with 100% passing the 1 inch sieve shall be tested by ASTM C 131. Use grading most representative of ballast material gradation.
- The limit for bulk specific gravity is a minimum value. Limits for the remainder of the tests are maximum values.

4.3 Chemical Analysis of Railway Ballast

- No specific chemical analysis is considered essential for the evaluation of granite, traprocks or quartzite type materials provided that the materials are properly defined by applicable methods. The magnesium carbonate ($MgCo_3$) content of carbonate materials shall be tested and defined in accordance with ASTM C 25. The different carbonate materials are defined,



- dolomitic limestones : magnesium carbonate (MgCo_3) content of 28% to 36%
- dolomites : magnesium carbonate values above 36%
- limestones: magnesium carbonate values below 28%

Standard Methods of Chemical Analysis of Limestone, Quick Lime and Hydrated Lime, or other test methods as may be approved and directed by the authority.

- b) Steel furnace slags consist essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese, calcium and magnesium. Steel furnace slag having a content of more than 45% calcium oxide and/or a combined composition of more than 30% of the oxides of iron and aluminum should not be used.
- c) Iron blast furnace slag consists essentially of silicates and aluminosilicates of calcium and other bases. Iron blast furnace slag having a content of more than 45% of the oxides of calcium or a combined composition of more than 17% of the oxides of iron and aluminum should not be used.

4.4 Other Quality Assurance Measures

- a) The Los Angeles Abrasion Test is a factor in determining the wear characteristics of the ballast material. As directed in the specification, the larger ballast gradations should be tested in accordance with ASTM C 535 while ASTM C 131 is the wear test for smaller gradations. The Los Angeles Abrasion Test relates to the abrasive wear resistance of the aggregate. Excessive abrasion loss of an aggregate will result in reduction of particle size, fouling of the ballast section, reduction of drainage and loss of supporting strength of the ballast section.
- b) Processed ballast shall be washed and/or rescreened as necessary to remove fine particle contamination as defined by the specification or as directed by the individual railway company prior to stockpiling in operations using stockpiles or immediately prior to loading operations.



- c) The manufacturer shall provide the inspector with such assistance, materials, and laboratory testing equipment as necessary to perform on production site gradation and percent passing No. 200 Mesh Sieve analysis. Performance of these tests at the time of an unscheduled inspection visit is the right, but not the duty, of the inspector.
- d) In the event any two individual samples fail to meet the gradation requirement, immediate corrective action shall be taken to restore the production process to acceptable quality. The purchaser shall be advised in writing of the corrective action being taken. In the event of repeated failures, i.e. two or more samples failing in two successive shipments, the purchaser reserves the right to reject the shipment.
- e) A full range of laboratory testing, as defined by this specification, shall be performed at least two times a year or as directed by the authority, to insure the quality of the material being produced. If the supplier changes the location of the source or encounters changes within the supply source, laboratory testing should be performed on the new material to ensure compliance with specifications.
- f) Prior to installation, the supplier shall provide the authority with certified results of ballast quality and gradation as conducted by a testing laboratory accepted by the authority. The supplier shall receive approval of the authority for the Testing Laboratory prior to performing the aforementioned tests.

5. Australian Standard for Railway Ballast Specifications

5.1 The Gradation of Ballast - The gradation of ballast as per **Australian Standard (AS 2758.7:2015)** is summarized in Table 7 below.

Table 7: Gradation of Ballast as per Australian Standard [4]

| Sieve Size (mm) | % passing by weight | | | |
|--------------------|---------------------|-----------|-----|-----------|
| | Nominal size, mm | | | |
| | 60 | 60 Graded | 50 | 50 Graded |
| 63.0 | 100 | 100 | - | 100 |
| 53.0 | 85-100 | 85-100 | 100 | 95-100 |



| | | | | |
|-------|-------|-------|--------|-------|
| 37.5 | 20-65 | 50-70 | 90-100 | 35-70 |
| 26.5 | 0-20 | 20-35 | 20-55 | 15-30 |
| 19.0 | 0-5 | 10-20 | 0-15 | 5-15 |
| 13.2 | 0-2 | 2-10 | - | 0-10 |
| 9.50 | - | 0-5 | 0-5 | 0-1 |
| 4.75 | 0-1 | 0-2 | 0-1 | - |
| 1.18 | - | - | - | - |
| 0.075 | 0-1 | - | 0-1 | 0-1 |

Note:

- a) Particular attention should be given to avoiding segregation of railway ballast during handling, transportation and ballast placement, as segregation could affect the ability of the ballast to interlock and distribute loads in place in the track.
- b) When using graded ballast additional care may be required, as the ballast could have a greater tendency to segregate due to its broad grading range across a number of particle sizes.

5.2 General Requirement

a) Particle Shape:

The proportion of misshapen particles in the fraction of ballast material retained on the 9.50mm test sieve, using a 2:1 ratio, shall not exceed 30%

b) River Gravel:

River Gravel or crushed river gravel shall not be used as railway ballast.

5.3 Durability - Durability assessment to be done by any one of the sets of test methods given below.

a) Aggregate Crushing Value and Wet Attrition Value

The fraction of material passing the 26.5 mm test sieve and retained on the 19.0 mm test sieve, shall not exceed 25%. Alternatively aggregate crushing value test may be conducted on the fraction of material passing the 53 mm sieve and retained on the 37.5 mm sieve. In this case the aggregate crushing value of the ballast



material, determined in accordance with AS 1141.21, should not exceed 30%. The wet attrition value of the ballast material for the fraction of material passing the 53.0 mm test sieve and retained on the 37.5 mm test sieve shall not exceed 6%.

b) Aggregate Crushing Value and Los Angeles Value

The aggregate Crushing Value is to be determined as mentioned above and the Los Angeles value shall not exceed 25.

5.4 Chemical Analysis of Railway Ballast

- a) Weak Particles (Contaminant Test) The proportion of the weak particles shall be less than 5%.
- b) Electrical Resistivity - If it is suspected that the conductivity of ballast to be supplied to such track could interfere with track circuits (e.g. metallurgical slag or source rock with high sulphide mineral content), the ballast should be tested for electrical resistivity and the minimum specified electrical resistivity is 60 ohm-m.

6. Canadian National Railways Specification of Crushed Ballast

The salient features of Canadian National Railways Specification of Crushed Ballast (12-20C, July 2003)

6.1 Gradation of Ballast

The ballast shall be tested as per ASTM C 136 and ASTM C 117 (for material passing the No. 200 sieve). The gradation of ballast and trowelling stone shall confirm to the grading requirement mentioned in Table 8 below.

Table 8: Gradation of Ballast [16]

| Sieve Size (mm) | Class 1 & 2 Ballast | Trowelling Stone |
|-----------------|---------------------|------------------|
| 63 | 100 | - |
| 50 | 7090 | - |
| 37.5 | 4070 | - |
| 25 | 025 | 100 |
| 19 | 03 | 90100 |
| 12.5 | - | 1555 |
| 4.75 | - | 05 |
| 0.75 | 01 | 01 |



6.2 General Properties

The ballast and trowelling stone shall be composed of hard, strong and durable particles and clean from clay and shale and from an excess of dust or elongated pieces. The crushed rock ballast or trowelling stone shall have at least 75% of the particles by mass with two or more fractured faces and at least 98% of the particles by mass with one fractured face. The above percentages will be required within each sieve size coarser than 3/4-inch (19 mm).

The crushed rock ballast or trowelling stone shall contain less than 30% by mass of flat pieces. The Flakiness Index is determined as per British Standard-812.

6.3 Physical and Durability Properties

The physical and durability properties of ballast are summarized in Table 9 below.

Table 9: Physical and Durability Properties of Canadian ballast

| Property | Class 1 Ballast and Trowelling Stone | Class 2 ballast | Test Method |
|---------------|--------------------------------------|--------------------|-------------|
| Absorption | 0.5% | | ASTM C 127 |
| Soundness | <7.0% at 5 cycles | <10.0% at 5 cycles | ASTM C88 |
| Abrasion Loss | <20% | <30% | ASTM C 535 |

6.4 Other Provisions

- Electrical Resistivity -Ballast resistivity shall be more than 3000 ohm-meters.
- During production the Producer shall carry out the grading test twice per day, the abrasion loss test once on each 10,000 metric tonnes of production, and all other tests once each 30,000 metric



tonnes of production thereafter. The ballast or trowelling stone shall be tested more frequently if there is any indication of a change in quality.

- c) The Inspector shall have, during working hours, free entry to all parts of the producer's plant and laboratory facilities used in the production or testing of material ordered to this specification.

7. European Standard Ballast specification

7.1 Gradation of Ballast

The gradation of ballast shall confirm to the grading requirement mentioned in Table 10 below.

Table 10: Gradation of Ballast as per European Standard 13450, 2002 [17]

| Sieve Size (mm) | Railway Ballast Size 31.5 to 50 mm | | | Railway Ballast Size 31.5 to 63 mm | | |
|-----------------|------------------------------------|--------|--------|------------------------------------|-------|-------|
| | % passing by mass | | | | | |
| | Grading Category | | | | | |
| | A | B | C | D | E | F |
| 80 | 100 | 100 | 100 | 100 | 100 | 100 |
| 63 | 100 | 97-100 | 95-100 | 97-99 | 95-99 | 93-99 |
| 50 | 70-99 | 70-99 | 70-99 | 65-99 | 55-99 | 45-70 |
| 40 | 30-65 | 30-70 | 25-75 | 30-65 | 25-75 | 15-40 |
| 31.5 | 1-25 | 1-25 | 1-25 | 1-25 | 1-25 | 0-7 |
| 22.4 | 0-3 | 0-3 | 0-3 | 0-3 | 0-3 | 0-7 |
| 31.5 to 50 | ≥50 | ≥50 | ≥50 | - | - | - |
| 31.5 to 63 | - | - | - | ≥50 | ≥50 | ≥50 |

7.2 Physical and Durability Properties - The physical and durability properties of the ballast in U.K. Railways are summarized in Table 11 below.

Table 11: Physical and Durability properties of U. K. Rail Ballast

| Property | | Max % |
|------------|--------------------------|-------|
| Shape | Flakiness Index | 40 |
| | Elongation Index | 40 |
| Strength | Aggregate Crushing Value | 22 |
| Durability | Wet attrition Value | 4 |



8. Comparison of IR Ballast with International Practices

8.1 Gradation Comparison

The comparison of Ballast gradation is shown in Fig 1. From gradation curve % finer for various sizes ranging from 80 mm to 0.075mm have been taken.

The gradation of ballast of IR has been compared with other countries and it has been observed that:

- Indian railway Ballast is Poorly Graded as compared with other countries
- The void ratio of IR Ballast will be very high as it is uniformly graded with large size particles and it does not allows finer particles of size less than 20 mm.

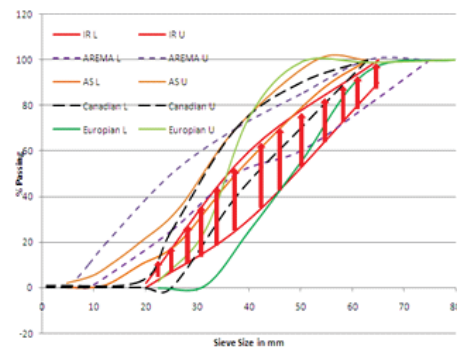


Fig 1: Comparison of Gradation curve of ballast of IR, AREMA, Australian, Canadian and European Standard

8.2 Comparison of Abrasion tests

Railroad ballast typically is a coarse, crushed rock with particle sizes in the range of 0.25 inch(6.4 mm) to 2.5 inch(64 mm).Currently, there are three abrasion tests used by various railways. These are the Los Angeles abrasion (LAA) test, the Mill abrasion (MA) test, and the Deval, or British Standard, attrition test. The LAA test has long been used as the primary abrasion test for ballast in North America. Even so, many engineers believe that the LAA test is not sufficient, and others that it is not useful. The Deval test is the primary test used by British Rail. The MA test, which complements the LAA test, has been proposed as an abrasion test for North America. It is similar to the Deval test.

The LAA value is the amount of material less than the No. 12 sieve (1.70 mm) generated by the test as a percentage of the original sample weight. The MA value is the amount of material finer than the No.200 sieve (0.075 mm) generated by the test as a percentage of the original sample weight. The Deval test [3] is similar in



character to the MA test. The inclined axis may provide some particle impact along with the rolling action found in the MA test. The wet attrition value is the mass of sample generated finer than the 2.36-mm size expressed as a percent of the initial sample mass.

Klassen et al [10], conducted a study of ballast degradation in track for the Canadian Pacific Railroad (CPR). He concluded that relative performance of different rock type as ballast could be represented by abrasion number (AN) defined as (LAA value + five times MA value). Based on his work, the CPR established a new ballast specification using AN. The CPR specification also included a procedure for the MA test adopted from Raymond's work.

The results of the LAA tests for every material are given in Table 13, ranked from 1 to 14 (1 = lowest loss ratio). Table 6 also includes a ranking of the available MA test results. For reference, the abrasion number (AN) has also been listed and ranked.

Table 13: Ranking of abrasion test results [13]

| Material | LAA | | MA | | AN | |
|----------------|-------------------|----------|-------------------|----------|-------------------|----------|
| | Rank ^a | Value, % | Rank ^a | Value, % | Rank ^a | Value, % |
| Granite | 1 | 17 | 6 | 5.6 | 3 | 45 |
| Quartzite 2 | 1 | 17 | --- | --- | --- | --- |
| Quartzite 1 | 2 | 20 | 1 | 1.9 | 1 | 30 |
| Monzonite | 3 | 21 | 3 | 2.3 | 2 | 33 |
| Gneiss 1 | 4 | 23 | 2 | 2.0 | 2 | 33 |
| Gneiss 3 | 4 | 23 | --- | --- | --- | --- |
| Dolomite 1 | 5 | 24 | 8 | 6.8 | 5 | 58 |
| Gneiss 2 | 6 | 25 | 5 | 5.4 | 4 | 52 |
| Micrite | 6 | 25 | --- | --- | --- | --- |
| Biomicrodite | 7 | 27 | 9 | 7.0 | 6 | 62 |
| Microsparudite | 8 | 33 | 11 | 11.4 | 9 | 90 |
| Slag | 9 | 35 | 7 | 6.5 | 7 | 68 |
| Dolomite 2 | 10 | 36 | 10 | 10.1 | 8 | 87 |
| Basalt | 11 | 48 | 4 | 4.0 | 7 | 68 |

^a 1 = lowest loss (%)

The ranking of rock types is not the same in the MA and LAA tests. This may be expected based on the rock characteristics as determined in the petro graphic examination since the LAA test primarily produces fractured particles larger than the No. 200 sieve (0.075 mm), while the MA test primarily produces fines smaller than the No. 200 sieve. The tests are therefore potentially complementary. For this reason Klassen at CP Rail [10] has defined



the abrasion number (LAA + 5 MA). The ranking indicated by AN seems to be more reasonable.

8.3 Ballast service life Prediction

IR codes and manuals do not discuss & specify any parameter related to the life of the ballast; however IRPWM specify the recouplement of the deteriorated Ballast in the track after a certain passage of traffic. Deep Screening of ballast is a process of renewal of undersized/crushed/ rounded/fouled ballast from railway track with good quality of angular, cubical and appropriate grade of ballast. As per IRPWM Para-238, Deep Screening is to be carried out in following situations by providing full ballast cushion:

- (a) Prior to complete track renewal.
- (b) Prior to through sleeper renewal.
- (c) Where the caking of ballast has resulted in unsatisfactory riding.
- (d) Before converting existing track, fish plated or SWR into LWR or CWR; or before introduction of machine maintenance, unless the ballast was screened in recent past.
- (e) The entire track must be deep screened at least once in ten years.

This activity can be done manually or mechanically. Manual Deep Screening is done as per para 238 (2) e of IRPWM. While manual deep screening sieve of 20 mm size is used and all the retained particles are put back in the track.

The mechanized Deep Screening work can be done using Ballast Cleaning Machine (BCM). The machine have cutter bar which cuts the fouled ballast get it transported to the set of Sieves (80mm, 50mm and 30mm) from where the oversize and under size ballast are thrown away and required size ballast (80mm > Ballast > 30mm) comes in the track. Mechanized screening is a better solution for screening of ballast as excavation depth is ensured and bed is leveled.



Feldman and Nissen (2002) proposed a method of estimating ballast cleaning cycles for a particular section of track. A similar and more rationalized technique was proposed by Daniela (2005) for predicting the permitted life as a function of the proposed fouling index. Daniela (2005) proposed the equation 1 for calculating fouling index. It is possible to achieve an efficient estimate of the ballast fouling rate and the ballast cleaning cycles for a track section or rail corridor.

$$FI_D = \frac{D_{90}}{D_{10}} \quad (1)$$

This method provides the thorough monitoring of ballast fouling. Samples should be taken every two kilometers along a section of track so as to permit an average value to be computed for the fouling index (FI_{D-av}) for the required track section. A fouling rate (FR) is then calculated by dividing the average F_{D-av} value by the ballast's life (LB) since undercutting/deep screening was last performed on that track section.

$$FR = \frac{FI_{D-av}}{LB} \quad (2)$$

The permitted ballast life or ballast cleaning cycle will be then calculated by dividing the fouling limit for highly fouled ballast (FI_{D-HF}) by the fouling rate for the required track section.

$$LB_{all} = \frac{FI_{D-HF}}{FR} \quad (3)$$

The method used to predict the permitted ballast service life is based on the proposed fouling index, which takes in account both the drainage capability and the resilient characteristics of the ballast layer. This seems to be more efficient prediction of the ballast cleaning cycle.

In Indian Railways there is criteria of ballast renewal at every 10 year (para 238 of IRPWM) irrespective of degradation pattern

8.4 Comparison of Other Properties

While comparing Indian Railway Standard with other railways standard following observations have been made:



- a) IRS GE-1 2016 specifies Aggregate Impact Value test as per IS 2386 Part IV 1963. This test is for aggregate of size 10mm to 12.5 mm which would not represent the exact ballast. Australian Railway Standard AS2758.7 recommends use of the fraction of material passing the 53 mm sieve and retained on the 37.5 mm sieve. Indian Railways needs to modify this provision.
- b) IRS GE-1 2016 has no specification for specific gravity, bulk density, particle density, and soundness whereas other railways have this specification.
- c) IRS GE-1 2016 specification for particle shape, flakiness and elongation are subjective whereas other railways have well defined methodology.

9. Discussion

The improvement of the performance of the substructure appears to be an economical approach to increasing the strength of the track system. More emphasis must be placed on the quality and type of ballast materials used in the substructure. Improved geotechnical techniques and test methods together with a better understanding of soils have provided the opportunity for ongoing tests to evaluate the quality and support characteristics of ballast materials.

A laboratory test to simulate performance and evaluation of ballast materials in track has not been developed yet. However ongoing current ballast tests dedicated to the correlation of laboratory tests to field performance indicate that we may be approaching our goal. The results of these testing programs could guide further improvement of the ballast specification in the future.

The preferred ballast materials would be a clean and graded crushed stone aggregate and/or processed slag with a hard, dense, angular particle structure providing sharp corners and cubicle fragments with a minimum of flat and elongated pieces. These qualities will provide for proper drainage of the ballast section. The angular material will provide interlocking qualities which will grip the ties more firmly to prevent movement. Flat and elongated



particles in excess of the maximum as specified in the specification could restrict proper consolidation of the ballast section.

Track loading patterns and traffic density, weight of the rail section, grades, the cross section of the ballast section, the sub-ballast and the roadbed interaction together with climatic conditions are major considerations in the performance of ballast materials. A well compacted subgrade and sub-ballast section will provide stable and uniform areas for the distribution of the track loads throughout the ballast section.

The ongoing ballast and roadway tests at TTCI (formerly FAST facility) have also confirmed that the Los Angeles Abrasion Laboratory Test is not indicative of the field performance of ballast materials. We must bring to the attention of the engineer in-charge that considerable variables exist with many laboratory physical testing methods and procedures and the Los Angeles test is no exception. Not only do variables exist between individual tests, but between testing laboratories as well.

10. Conclusion

The paper presents an overview of the various specifications of the ballast like gradation, chemical & physical properties and abrasion test of rail bed ballast as per the different world railway standard codes and manuals.

IR standard code and manuals are following the same ballast gradation standards as prevailed from the time of East India Company, which needs to be reviewed in view of today's requirement of mixed traffic conditions and the increasing traffic on the IR network. The abrasion value of the ballast is determined by LAA test for IR ballast which also needs to be reviewed because the ballast size used in LAA is not the size of ballast which is used at the track in service. On the other hand world Railways have proposed other tests for the abrasion value. Indian Railway Permanent Way Manual (IRPWM) does not provide any parameter to be determined & analysed for the assessment of the life & quality of ballast with the



passage of service time. Many researchers proposed the calculation of Fouling- Index for the determination of the quality of ballast and the ballast life can also be determined.

Some of the suggestions are:

- i. Indian Railways needs to adopt some strength parameters like specific gravity/density of ballast in the specifications.
- ii. Gradation is second important aspect which needs a revision, other railways where heavy axle loads are running are allowing ballast size upto 9 mm whereas we have restricted it to 20 mm.
- iii. For screening, criteria need to be changed from 10 years to some quantitative assessment such as fouling index / fouling percentage / ballast breakage Index etc.

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