GNH Journal of Construction Technology & Management (2021) 02, 23-27

# Study on Riverbed Sediments as Road Construction Material: GSB and WMM

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**Abstract:** Pavement or road surface is a durable surface material laid on the prepared layers to sustain traffic load. Pavement is composed of different types of layers which influence the durability. These layers are termed as sub-base and base course which function as structural component and also act as drainage layer called Granular Sub-Base (GSB) and Wet Mix Macadam (WMM). The study introduces Toorsa riverbed sediment deposits as road construction materials which are commonly stipulated in Bhutan standard as GSB and WMM. The study aims to provide experimental and technical investigation to assess suitability as road construction materials. The variability of the aggregate sizes from natural sources is uncertain and variations gap in sizes are expected to be large compared to crushed aggregates produced in manufacturing plants. As per standard, coarse or close graded 75mm and 53mm down gauge aggregates are utilized for GSB and WMM respectively. To this end, experimental investigation is carried out to ascertain the quality, grading characteristics and corresponding Job Mix Formula (JMF) for particular trials are illustrated so as to qualify for road construction material.

*Keywords: Sediments, Granular Sub-Base, Wet Mix Macadam, Job Mix Formula*

Received 18 March 2021; accepted 10 May 2021. Available online 18 May 2017

## Introduction

Road base is defined as a layer of bound materials to give structural integrity to a pavement. In the current study, experimental tests are conducted for recommended structural layers sub-base and base course used in Bhutan. The construction materials used for these two bases are mainly coarse and fine aggregates. Initially, assessment is carried out to verify the quality of the materials with the threshold values suggested by the IS code and the Job Mix Formula are deduced through quantitative analysis by proportioning the mix as per the grading requirements and the resulting outcomes are recommended through this study. Tests in terms of physical characteristics are performed which includes specific gravity, moisture content, grain size distribution (IS: 2386-Part 3, 1963); (IS:2720-Part 4, 1985), and mechanical properties (IS : 2366-Part 4, 2002): Impact and abrasion values. In addition, during the execution, compaction and water content becomes paramount parameters for proper densification of the sub-base and the base course and hence compaction behavior of the structural materials is studied and discussed. This plays an important role in determining the functional and structural durability of the pavement.

Flexible pavement are most common types of roads in Bhutan owing to geographical settings and topographical conditions. The primary means of transportation in the country in mainly by transport network to support strategies for socioeconomic development. As of 2019, the road network consists of about 18,362.69 km, comprising 15.29% of primary and secondary national highways (MOWHS, 2017) which serves as the back born for transport network. Flexible pavement is composed of three-layer structure- subgrade, unbound and bound layer (Sarkar & Dawson, 2017); (IRC, 2018); (DES, 2020). The unbound layer commonly known as the subbase or base course layer usually comprises a GSB or WMM just above the subgrade layer in which materials are held together by physical interlock and suction through compaction and water content. A pavement layer is structurally stable, if it is able to distribute the stresses due to wheel load per unit area of the depth of the layer by keeping the elastic deformation within the permissible limits (Math et al., 2016). Hence, it is likely that the pavement sustains large number of cyclic loading during the design period. GSB and WMM are main components of pavement, hence, there is need of stable and non-yielding pavement structure to sustaining the traffic load and optimize the usage of materials for economic construction (Math et al., 2016). Also, one of the most essential function of the GSB and WMM layers is to provide adequate drainage to achieve longer durability of the pavement (Schaefer et al., 2008). For proper drainage, the layers should have sufficient permeability which allows the flow of water through it. The grading characteristics enhances the permeability characteristics of effective drainage layers and keeps the subgrade dry. To achieve these factors, various laboratory test was conducted in accordance to IS code to ensure the quality.

**Materials and Method**

In this study, the samples of natural aggregates sizes approximately ranging from 100mm to 4.75mm are collected from Toorsa riverbed sediment deposit which extends ~5 km between Phuentsholing town towards Amochhu bridge as shown in Figure 1. The sampling was done from three extraction points between the mentioned stretch allocated by National Resource Development Corporation Limited (NRDCL).

The construction aggregates in Bhutan originates from different sources in the regions from natural quarry, mining and river bed materials. Natural resources such as stone boulders and sand are largely consumed in construction industry. In Phuentsholing alone, the consumption of stone boulder and sand is as high as 90,000 cu.m and 75,000 cu.m per year respectively (Figure 2). Boulders are commonly used for production of crushed aggregates of various sizes or directly used in the construction sites.

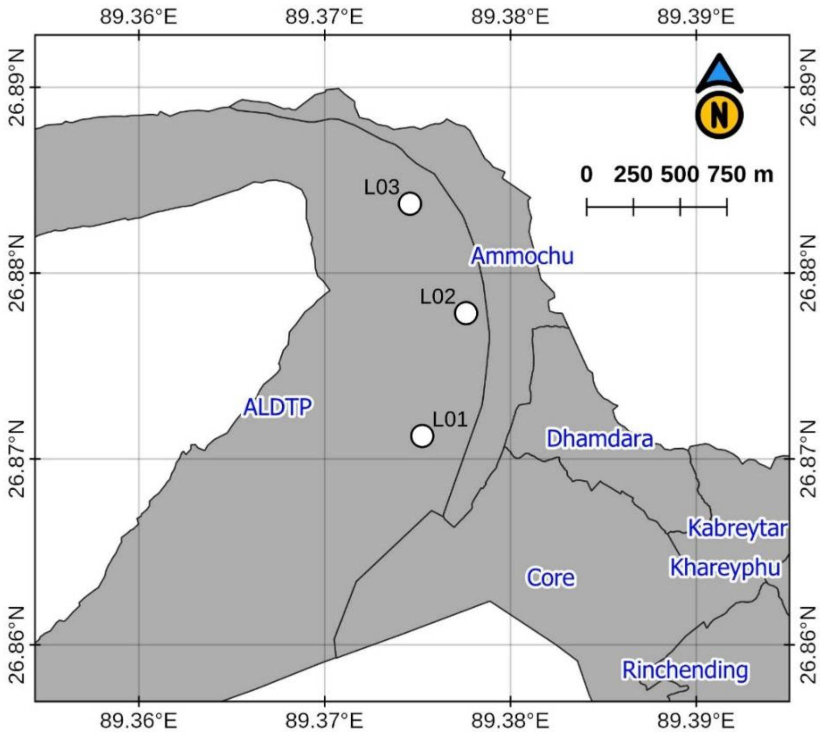


**Figure 1.** Locations (L01, L02 and L03) of extraction point approved by NRDCL under Phuentsholing Thromde

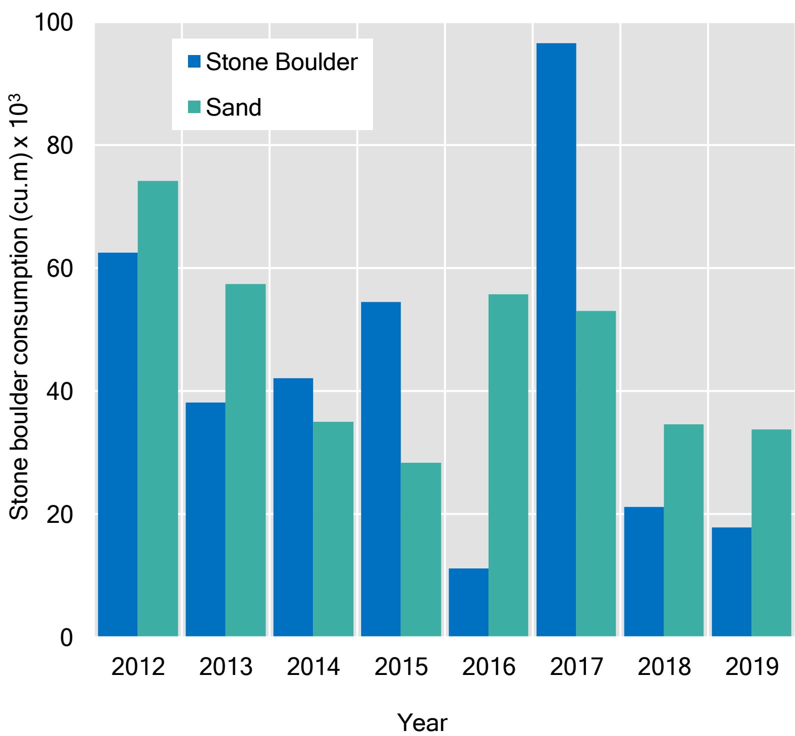


**Figure 2.** Annual stone boulder and sand consumption from Toorsa river bed (http://nrdcl.bt/)

**Figure 3.** Stock of Toorsa riverbed sediments as construction material

**Table 1.** Summary of laboratory test conducted for GSB and WMM materials from Toorsa riverbed

| Test | Description | References |
|---|---|---|
| Sieve analysis | Determines the particle size distribution in a sample and defines the grading characteristic. | IS:2720 (Part 4) - 1985 |
| Impact | Aggregate Impact Value (AIV) of aggregates which provides a relative measure of the resistance of an aggregate to sudden shock or impact. | IS: 2386 (Part 4) - 1963 |
| Abrasion | Los Angeles abrasion test is usually conducted to find the toughness and the abrasion character of the paver block, by subjecting the sample paver block to impact, abrasion, rotating and grinding in the steel rotating drum with 6 numbers of spherical weight balls. | IS: 2386: (Part 4) - 1963 |
| Shape | Flakiness Index of aggregate is the percentage by weight of aggregate particles whose least dimension is less than 0.6 of their mean dimensions. Elongation index test of an aggregate is the percentage by weight of particles whose greatest dimensions is greater than 1.8 times their mean dimensions. These tests are applicable to aggregates having size larger than 6.3mm. | IS 2386: (Part 1) - 1963 |
| Water absorption | The moulded samples are soaked in water for 24 hours and dried in an oven and air dried for another 24 hours. In both the cases, the water absorption is determined. The percentage difference in weights to the dry weight is water absorption. | IS: 15658 - 2006 |
| Specific gravity | The ratio of the weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of water at the stated temperature. | IS: 2386 (Part 3) – 1963 |
| Compaction | Measure of dry density corresponding water content at different loading conditions | IS: 2720 (Part 8) - 1983 |

In current study, experimental investigation was conducted to primarily determine index, physical and mechanical properties of Toorsa riverbed sediment. The quality of this materials when used as a construction material requires qualification to standard requirements set by the standards. Table 1 presents the summery of laboratory test conducted in current study according to IS codes.

## Results and Discussion

### *Quality Assessment*

For any construction works, quality control measures and assurance are must and it plays vital role in maintaining durability of the built system. Surface side drains and sub-surface drainage greatly help in enhancing the durability and functional integrity of the road network system. Most commonly, due to poor drainage systems, the development of multiple surface distresses are rapid deteriorating serviceability condition of the pavement (Jayakumar & Soon, 2015); (Din et al., 2019).

GSB and WMM not only acts as an integral structural part of the pavement but also facilitate proper sub-surface drainage. However, if gradation of any of these components are not properly maintained as per the specification, the life span of the pavement sustains only single monsoon. Gradation indirectly plays important role in reducing pavement distresses and subsequent rutting (Chilukwa & Lungu, 2019). Figure 4 is a typical example of pavement failure in Bhutanese roads with poor composition of sub-base or base materials laid for the pavement.

**Figure 4.** Post and pre-condition of pavement surface and base layers due to poor quality control measures

Specifications for Building and Road Works (DES, 2020) offers wide variety of materials to be used for GSB and WMM. Some of these materials mentioned are natural sand, moorum, gravel, crushed stone, or combination thereof depending upon the grading required. Further, materials like crushed slag crushed concrete, brick metal and kankar pointed out which may be used with the specific approval of the Engineer. However, those materials shall be free from organic or other deleterious constituents and conform to one of the three grading (DES, 2020). Commonly, crushed aggregates from crusher plant, river bed aggregates and natural aggregates are also used in Bhutan. To this end, to assess and assure the quality used for GSB and WMM, various laboratory tests are conducted in current study for Toorsa reverbed sediment to be used as road construction material. Test for mechanical properties of the coarse aggregates such as impact value, and abrasion tests are conducted to measure the hardness, toughness and resistance to wear and tear respectively. The test procedure for all these tests confirms to (IS : 2366-Part 4, 2002). Shape test is conducted according to (IS : 2386-Part I, 1963). The shape factor defined in this paper is combined index of flakiness and elongation indices. The permissible limits for the properties as per (DES, 2020) are presented in Table 2 and Figure 5.

**Table 2.** Specifications and quality index for GSB and WMM materials

| Sample ID | Impact value (%) | Abrasion value (%) | Shape factor (%) | Water absorption value (%) | Specific gravity |
|---|---|---|---|---|---|
| S-1 | 18.2 | 22.4 | 25.26 | 0.13 | 2.76 |
| S-2 | 23.1 | 20.5 | 24.3 | 1.42 | 2.78 |
| S-3 | 17.8 | 28.2 | 23.45 | 0.98 | 2.69 |
| S-4 | 25.2 | 33.2 | 20.62 | 1.56 | 2.74 |
| S-5 | 26.7 | 18.7 | 25.78 | 1.78 | 2.68 |
| S-6 | 16.85 | 26.3 | 19.66 | 0.24 | 2.57 |
| S-7 | 21.45 | 34 | 21.5 | 0.65 | 2.68 |
| S-8 | 26.4 | 16 | 18.57 | 1.52 | 2.58 |
| S-9 | 27.6 | 16.2 | 25.5 | 1.43 | 2.66 |
| S-10 | 21.2 | 21.5 | 20.85 | 1.36 | 2.53 |
| **Max. values (%)** | **30** | **30** | **40** | **2** | **2.5-2.8** |

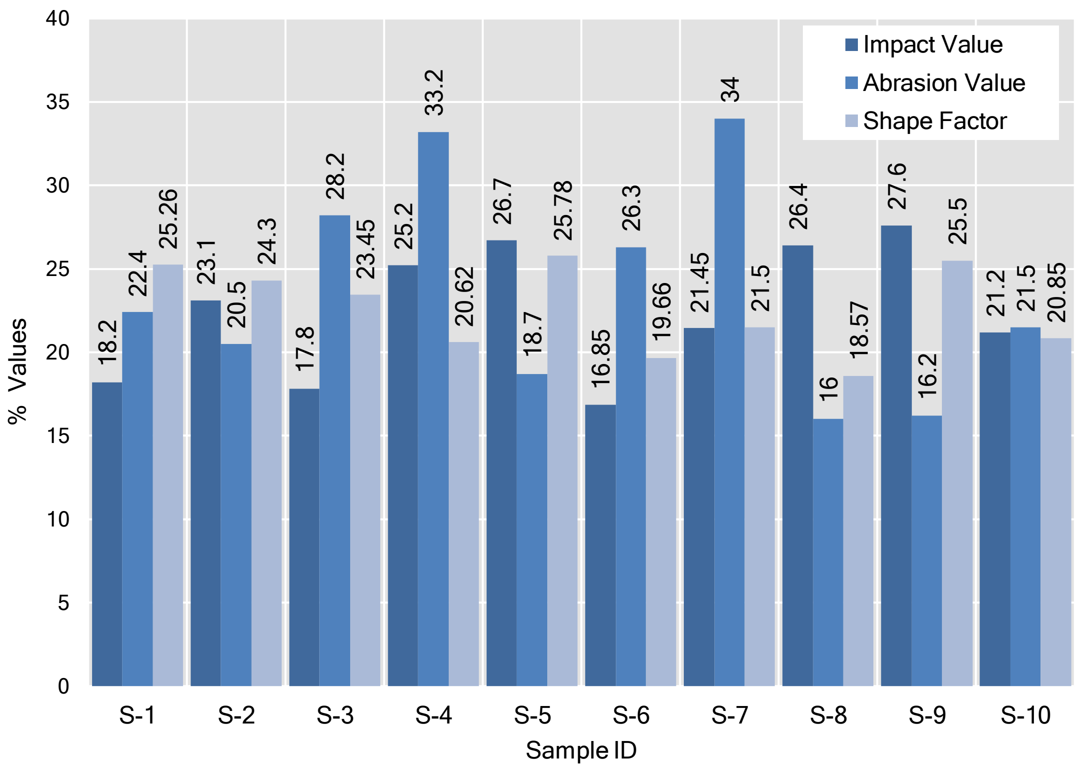


**Figure 5.** Variation of material quality indices of Toorsa riverbed sediment

Specifications for Building and Road Works (DES, 2020) specifies plasticity index not more than 6% for fraction less than 0.0425mm. The experimental study indicate that the Toorsa riverbed sediment contains substantial amount of coarser particles with very less amount of fines below 0.0425mm and exhibit non-plastic characteristics and does not influence the composition. However, for sand, the amount of silt content may be crucial to check the quality of sand to be used as construction material.

*Granular Sub-Base (GSB)*

As per the standard, the grade of each zones for GSB and WMM are indicated corresponding to Indian standard sieve sizes in descending order and it does not necessarily indicate the single size aggregates. Since, aggregates come in various coarse or close graded sizes practically from the natural sources and production plant or so, the Job Mix Formula shall be proposed between the sieve size limits specified by the standards in terms of nominal sizes. This argument and the relevancy can be understood well by determining the fraction required for each size of aggregates using percentage passing, which is usually calculated in terms of weight (%) as presented in Table 3 through sieve analysis (IS:2720-Part 4, 1985).

Since, the variation of riverbed aggregate mix contains uncertain sizes, the initial sieve analysis does not provide gradation as per the standard to be used as GSB or WMM materials.

This is also true for aggregates produced in different production plants; however, the trial mix may be reduced for processed aggregates supplied from the plants. The trial-and-error method conducted for producing grade I and II (Figure 6 and 7) of Bhutan standard is presented in Table 3. Four trials conducted for gradation of GSB show notable gaps among the particles range. This provides ample information on adding and reducing deficit or excess materials sizes respectively to finally obtain the graded proportion which provides JMF.

**Table 3.** Gradation of GSB-Grade I by trial-and-error method

| Sieve size (mm) | % Passing by Weight | | | | | Specifications (DES, 2020) | |
|---|---|---|---|---|---|---|---|
| | Trial-1 | Trial-2 | Trial-3 | Trial-4 | Grading curve | Lower limit | Upper limit |
| 75 | 83.61 | 90.12 | 80.10 | 95.88 | 100.00 | 100 | 100 |
| 53 | 56.02 | 85.18 | 69.32 | 90.61 | 88.51 | 80 | 100 |
| 26.5 | 50.00 | 79.64 | 58.71 | 81.71 | 70.64 | 55 | 90 |
| 9.5 | 35.62 | 68.58 | 38.14 | 67.71 | 54.47 | 35 | 65 |
| 4.75 | 26.59 | 57.91 | 34.66 | 56.51 | 44.26 | 25 | 55 |
| 2.36 | 17.22 | 33.60 | 27.20 | 51.24 | 33.19 | 20 | 40 |
| 0.425 | 12.54 | 16.80 | 16.42 | 30.81 | 22.98 | 10 | 25 |
| 0.075 | 8.36 | 4.15 | 1.99 | 7.41 | 4.68 | 3 | 10 |

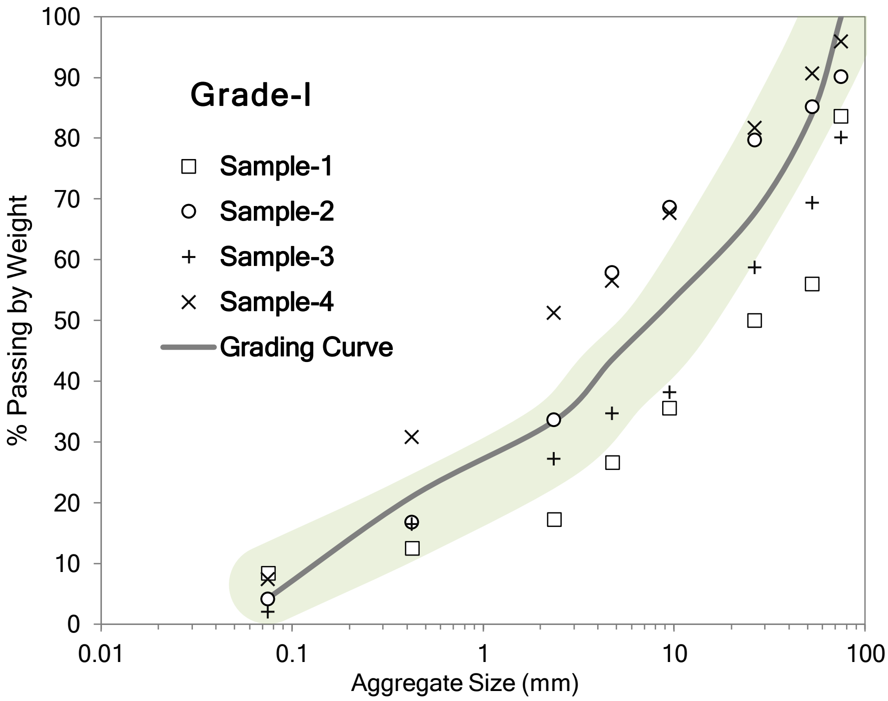


**Figure 6.** Grading characteristics of GSB grade-I

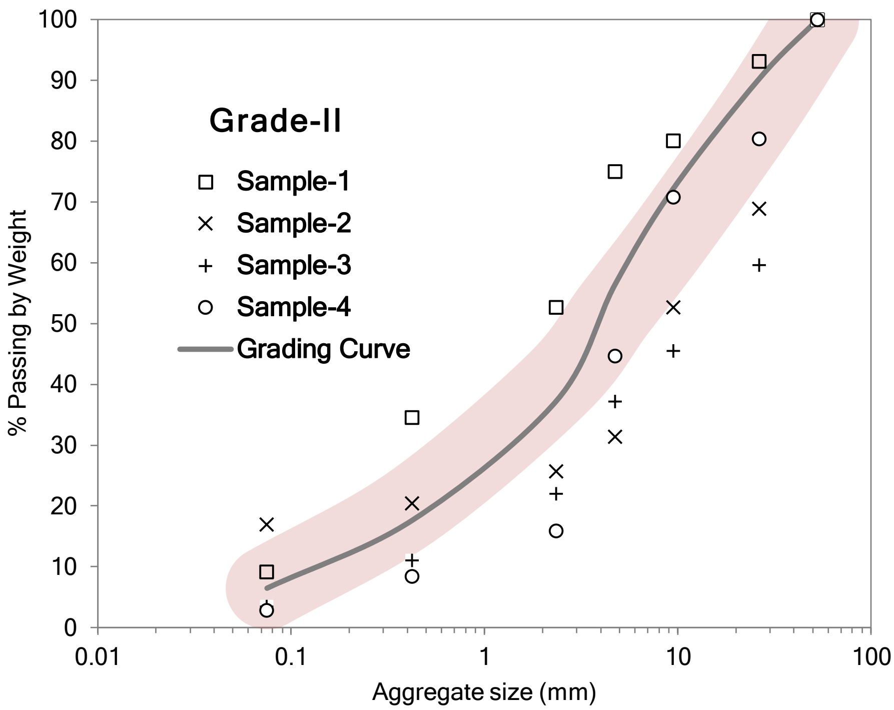


**Figure 7.** Grading characteristics of GSB grade-II

*Wet Mix Macadam (WMM)*

The process of gradation is similar to GSB, but the composition of WMM is finer with 53mm downgauge aggregates. The fraction passing 0.425mm sieve are also not plastic in which the plasticity is near or equal to zero. Usually, plastic nature of soil is more pronounced for fraction passing through 0.075mm containing clay content and this portion does not fall under the particle range in both GSB and WMM. The trial mix and gradation curve for WMM are presented in Table 4 and Figure 8 respectively.

**Table 4.** Gradation of WMM by trial-and-error method

| **Sieve size (mm)** | **% Passing by Weight** | | | | | **Specifications (DES, 2020)** | |
|---|---|---|---|---|---|---|---|
| | **Trial-1** | **Trial-2** | **Trial-3** | **Trial-4** | **Grading curve** | **Lower limit** | **Upper limit** |
| 53 | 95.10 | 100.00 | 100.00 | 91.86 | 100.00 | 100 | 100 |
| 45 | 86.25 | 69.14 | 76.05 | 76.92 | 96.32 | 95 | 100 |
| 22.4 | 81.92 | 54.07 | 66.67 | 74.90 | 74.23 | 60 | 80 |
| 11.2 | 67.23 | 51.11 | 65.52 | 68.68 | 53.07 | 40 | 60 |
| 4.75 | 59.13 | 44.69 | 53.74 | 53.74 | 35.89 | 25 | 40 |
| 2.36 | 13.75 | 14.32 | 38.12 | 31.51 | 22.09 | 15 | 30 |
| 0.6 | 3.58 | 6.42 | 26.05 | 26.15 | 11.04 | 8 | 22 |
| 0.075 | 1.51 | 2.96 | 8.24 | 22.13 | 3.68 | 0 | 8 |

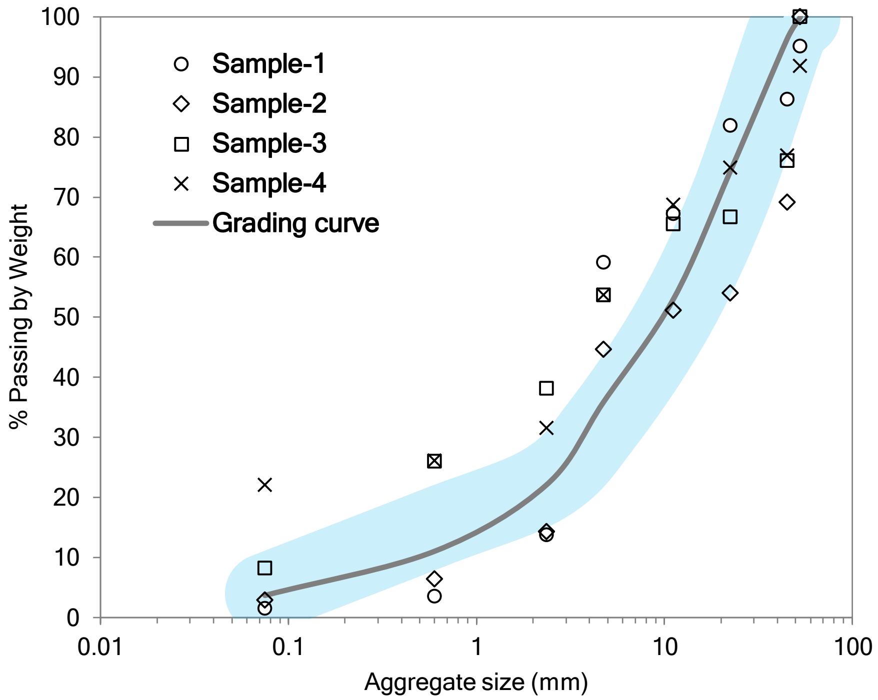


**Figure 8.** Grading characteristics of WMM

*Job Mix Formula for GSB and WMM*

The JMF is crucial as it provides the mix design proportions to be executed in the construction site especially when used as GSB and WMM for pavement. To the best of author's knowledge, the only method of preparing the mix design (JMF) is by conducting sieve analysis for number of trial mix to achieve the grading requirement due to variability of sizes and shapes of natural aggregates apart from the processed one. The JMF provided in this paper is of one instance for a collected sample and may not be applicable to other batch of samples, however, the reference trail mix can be comfortably determined to reduce the trail mix. The JMF for two grade GSB grade-I and WMM are presented in the following Table 5 & 6.

**Table 5.** JMF for GSB grade-I

| **Sub-base material** | | | **Gravel** | | **Sand** |
|---|---|---|---|---|---|
| Sieve Size (mm) | 75 – 53 | 53 - 26.5 | 26.5 - 9.5 | 9.5 - 4.75 | 4.75 - 0.075 |
| Job Mix Formula (JMF) % by Weight | 16.66 | 17.07 | 15.45 | 9.76 | 41.06 |
| Total (% by Weight) | | | **58.94** | | **41.06** |

**Table 6.** JMF for WMM

| Base material | | | Gravel | | Sand |
|---|---|---|---|---|---|
| Sieve Size (mm) | 53 - 45 | 45 - 22.4 | 22.4 - 11.2 | 11.2 - 4.75 | 4.75 - 0.075 |
| Job Mix Formula (JMF) % by Weight | 3.82 | 22.93 | 21.97 | 17.83 | 33.44 |
| Total (% by Weight) | | | **66.56** | | **33.44** |

*Compaction Behavior*

Modified proctor test refers to heavy compaction test, an improved version of standard (light) compaction test. The heavy compaction test was conducted so as to withstand and sustain heavy traffic load during the design period for which settlement could be one of the issues. The test was conducted as per IS code (IS: 2720-Part 8, 1983). To achieve the desired compaction, the laboratory test determines the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) (Tempa et al., 2021). Figure 9 shows the relationship between the dry density and moisture content for each of the samples. To determine the degree of densification at the site, field test could be conducted to achieve 98% of maximum dry density and (+) or (-) 2% of OMC for embankment, sub-grade, sub-base and base material (DES, 2020). For field density check, either core cutter or sand replacement methods can be used based on the type of soils. However, for GSB and WMM, sand replacement method is suitable as the soils are highly coarse compacted.

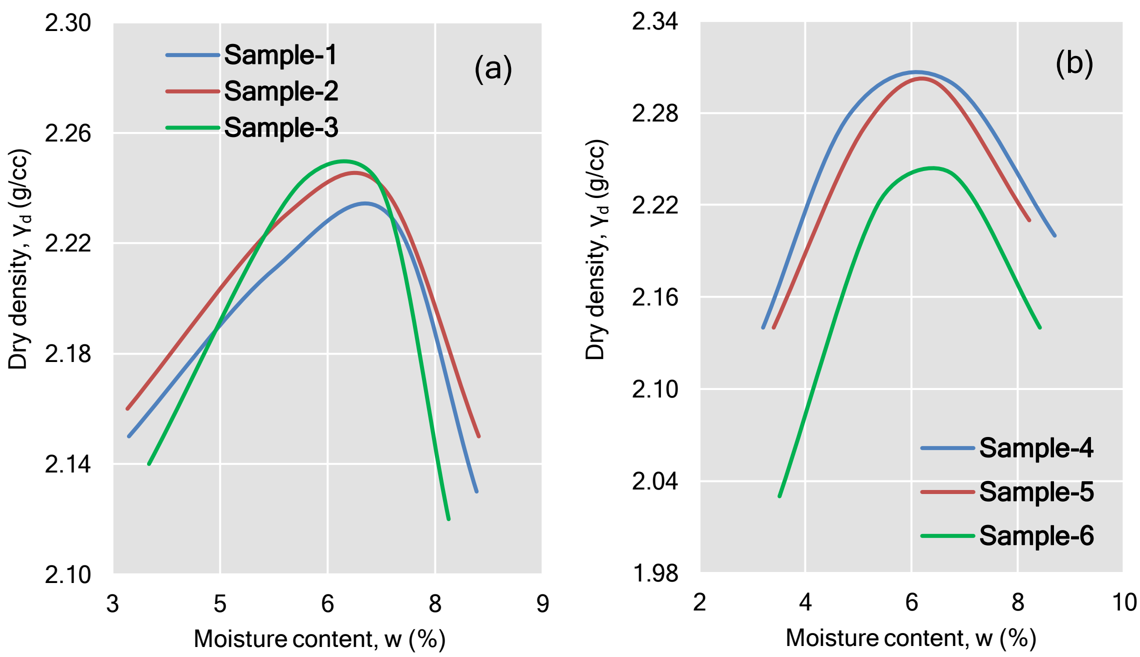


**Figure 9.** Compaction curve showing compaction behavior of the sediment; (a) GSB, (b) WMM

The Toorsa riverbed sediment exhibit high maximum dry density at low optimum moisture content. This is usually contributed by larger compaction effort in which MDD is achieved more towards dry side of the compaction curve (Gopal & Rao, 2000); (Mittal S. & Shukla, 2008); (Das, 2010); (Gurtug & Sridharan, 2015); (Yusoff et al., 2017). As per the test and considering an average result, MDD of 2.23 g/cc at 6.4% OMC for GSB and MDD of 2.32g/cc at 6.2% OMC for WMM is suggested as target values respectively.

## Conclusions

The study conducted on Toorsa riverbed sediments for suitability of use in road construction as GSB and WMM material indicates that the mechanical properties are well up to the standard requirement with acceptable specific gravity ranges and water absorption potential less than 2%. However, the flaky natural aggregates are in substantial amount and hence initial screening and prior shape test is highly recommended. This also applies to natural aggregates from different sources.

For JMF, the grading curves presented in this paper may be useful for both GSB and WMM in setting the initial trial mix. The other option could be usage of average value of upper and lower bound of grading curves as specified in the standards to initialize the trial mix. The mix proportion indicated in this paper however can also be used for batching purpose but gradation shall be checked before execution or laid at the site.

During the execution, the GSB and WMM layer should be compacted and densified to attain MDD and OMC. To verify this, field test should be conducted as per specifications laid in contract document or as per the latest Specifications for Building and Road Works.

**Acknowledgment:** The author would like to thank College of Science and Technology for test facilities. The data are the records of consultancy services carried out by the author.

**Funding:** The preparation of this manuscript did not receive any direct funding.

**Conflict for interest:** The author declares no conflict of interest.

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