Performance of Recycled Aggregate as Constituents of Base and Sub-Base Layers for Rural Roads

B. Sudharshan Reddy[1], Dr. G. Sreenivasa Reddy[2], Dr. C. Sashidhar[3]

[1]Ph.D Scholar, Department of Civil Engineering, JNTUA,Anantapuramu& Asst. Professor in Narsimha Reddy Engineering College, Hyderabad.
[2] Professor, Dept.of Civil Engineering K.S.R.M College of Engineering Kadapa, India.
[3] Professor, Dept.of Civil Engineering, JNTU Anantapur, India.

Article Info
Volume 82
Page Number: 16465 - 16472
Publication Issue:
January-February 2020

Article History
***Article Received**: 18 May 2019*
***Revised**: 14 July 2019*
***Accepted**: 22 December 2019*
***Publication**: 28 February 2020*

Abstract

This investigation is an endeavour to evaluate the performance of recycled aggregate as constituents of base and sub-base layers of rural roads in India. The physical and strength properties of the materials are tested and utilised to evaluate their performance. It is found that the physical properties of the Recycled Aggregate (RA) are unsatisfactory to those of crushed natural granite. The water absorption of 3.76% observed in RA is higher than the recommended 2%. The Recycled Aggregate (RA) is blended with the natural aggregates at 25%, 50%, 75%, and 100% replacement levels. The mixture with 100% crushed granite is utilised as control. The MDD of the aggregates is reduced with an increase in RA content and as a result, the OMC is increased. The CBR values of the aggregates reduced as the RA increased. The 0%, 25%, 50%, 75%, and 100% of RA had CBRs of 92%, 91%, 46%, 44%, and 28% respectively. Based on the CBR values and other tests conducted, exploitation of mixed RA for sub-base layers of rural roads is recommended. However, where mixed RA are utilised for base layers it should be limited to 25% inclusion.

Keywords:*CBR, compaction, base, recycled aggregates, sub-base*

I. INTRODUCTION

Human deeds remain the foremost cause of the global climate change due to heavy loads of greenhouse gasses released into the environment from these activities. As a result, critical environmental and health challenges are being experienced by humans and other creatures in recent times (Jimenez et al., 2012a). Various developmental strategies of different countries in the world require a continuous construction and re-enactment of accommodation and transportation infrastructures. This has made the construction activities an inevitable and endless human demand. Road construction is most important infrastructural provision because it links several economic activities within a country and across countries.

Provision of quality, drivable and measurable road networks both in cities and suburbs remains a very good indicator for sustainable development. It remains a necessity for human subsistence and development of global regions (Gilpin et al., 2004). Instead of reducing road construction activities, efforts are made towards making road construction more sustainable. The material flow for road pavement construction is a key area where sustainability strategies can be applied.

Below every pavement surface lies different materials, mostly unbound aggregates are utilised as the road base and sub-base materials. These materials are placed on the subgrade soil to ensure efficient transfer of traffic loads to the subgrade soil (Thomas et al., 2000). In order to withstand traffic

January - February 2020
ISSN: 0193-4120 Page No. 16465 - 16472

loading, the pavement layers are designed in such a way as to carry all traffic loads without unacceptable permanent deformations. The density and compaction characteristics of these materials are very necessary for fulfilling this objective. The performance of compacted granular materials utilised in pavement construction depends on these properties (Khabiri et al., 2016).

This performance is usually assessed based on the capability of the pavement to resist permanent deformation and remain functional under the worst traffic load imposed on it (Azadeganand et al., 2013; Cerni et al., 2012). It is then very important to examine into the properties of materials utilised as road base and sub-base layers of pavements. This is more important when recycled materials would be involved. Subsequently, in as much as utilising RA has been seen as a sustainable option, but ignoring the structural implications of such application can lead to unnecessary consequences. Undue failure of the pavement, unbearable ruts and cracks, inconvenient driving, reduced road user safety, among others, are the consequences of poor structural performance of pavement aggregates (Vali et al., 2017). For this reason, the properties of materials are utilised for road construction are carefully investigated in order to make sure adequate performance in pavement application.

During construction activities, large volumes of materials are involved. The amount of this construction iste production keeps rising annually (Disfani et al., 2014). These materials are usually made from natural resources which have the tendency of becoming scarce over time. Besides, the amount of energy spent in obtaining those materials as well as transporting them is very high, leading to a very high density of emissions into the atmosphere. For these reasons, utilising these natural resources has been considered not sustainable. A good attempt towards improving the sustainability of the construction industry is by utilisation of recycled materials (Aggarwal&Siddique, 2014). The construction industry, which is in demand of high volume of materials, also produces a very high volume of istes. These istes are of different types and forms; concrete, bricks, sand crete, marbles, among others. Reuse of these istes for construction activities can be both environmentally, economically, and socially beneficial (Wang et al., 2018). It could save the depleting natural resources, reduce construction cost, and reduce the atmospheric carbon burdens. Due to these benefits, use of RA from construction and demolition activities has been seen as a sustainable alternative to natural aggregates (Rahgozar et al., 2018; Seberian, et al., 2018).

In India, enormous quantity of these istes is generated yearly but only a little is being re-used in concrete production. Most construction istes in India are mixed in nature, comprising of all the materials utilised in the original construction. Different types of materials like concrete, stone masonry, ceramics, bricks, and sandcrete are being piled up together after demolition activities. For concrete applications, the concrete components of the istes are usually isolated from the debris for recycling purposes, leaving the rest dumped in landfills and open surfaces. The idea of recycling these iste materials together for road pavement sub-base and base application becomes very essential as it offers a more holistic re-use of the istes together (Jimenez et al., 2012b).

It is essential to make sure that the efficient and stability aspects of the sub-base and/or road base are satisfactory when using the RA (Vegas et al., 2011). The use of RA can only be practically adopted after extensive analysis on its physical and mechanical properties. Previous studies have investigated the performance of RA for road pavement applications. Investigations on geo-mechanical properties of construction and demolition iste by Arulrajah et al. (2012a) reveal that recycled concrete aggregates and recycled iste rocks exhibit similar or better properties than usual granular materials. A different

Published by: The Mattingley Publishing Co., Inc.

study on blend of recycled crushed bricks with recycled concrete aggregates and crushed rock found that the inclusion of crushed bricks had unenthusiastic effect on the strength properties of crushed rock and recycled concrete. The study recommended 25% inclusion of crushed bricks for pavement sub-base application (Arulraja et al., 2012b). Though the use of mixed RA may result in lesser properties of the aggregates, it is yet necessary to recycle larger amounts of these istes and enhance environmental sustainability and reduce reliance on depleting natural resources. For this reason, Jimenez et al. (2012b) proposed the use of mixed RA for rural roads and light trafficked roads.

In this study, the performance of RA from demolished structures in Hyderabad India has been assessed. The intention of the assessment is to make certain their feasible use in sub-base and base layers of rural road pavements in India. Various comparative combinations of natural crushed granite and RA are made and their engineering properties tested based on the specifications of MoRD and MoRT&H. Relationships between the properties are established and a new linear model is developed for prediction of CBR of the aggregate combinations based on their compaction characteristics. This study is significant as it reveals the performance of the mixed RA and their applicability in Indian rural roads.

II. MATERIALS AND METHODS

2.1 Materials

Two types of aggregates are utilised for this study, crushed granite aggregate and RA. The crushed granite is the natural aggregate conventionally utilised for many road construction activities in Hyderabad India. The RA utilised in this study comprised of a mixture of sandcretes, concretes, and crushed bricks collected from hips of construction and demolition istes in Hyderabad. Fig. 1 shows the picture of the demolished hips of aggregates. These construction istes are air dried and crushed with the laboratory scale jaw crusher to get the well graded RA utilised for this study.

Fig. 1 Aggregateistes from building demolitions.

The physical properties of the crushed granite and RA are determined. The performance tests are conducted on the combinations of the crushed granite aggregate and RA in order to estimate their performance as subgrade and road base materials. Section 2.2 summarises the major test methods adopted for this study.

2.2 Test Methods

Particle size distribution of the aggregates is determined based on the sieve analyses conducted according to Indian Standard (IS) 2386 (Part 1). The different sizes of the aggregates are further blended manually to comply with the specified grading limits. The shape of the coarse aggregates are also tested based on the flakiness and elongation indices tests conducted in accordance to IS 2386 (Part 1)

The specific gravity and water absorption of the aggregates are determined in accordance to IS 2386 (Part III). The impact resistance of the aggregates is also determined in accordance to IS 5640. The specific gravity and impact values of the aggregates give an indication of their strength properties. Stronger aggregates have higher specific gravities and lesser impact loss than weaker ones. The Los Angeles abrasion test is also conducted in accordance to IS 2386 (Part IV) to assess the hardness of the aggregates.

Published by: The Mattingley Publishing Co., Inc.

January - February 2020
ISSN: 0193-4120 Page No. 16465 - 16472

The modified Proctor compaction test is done on the aggregates in accordance to IS 2720 (Part IV). The compaction is done to determine OMC and MDD of crushed granite, RA, and different combinations of both crushed granite and RA. The materials are subjected to 5 layers of compaction with 25 blows at each layer. The rammer with a diameter of 50 mm, falling from 450 mm height and weighs 4.89 kg.

The CBR test is conducted in accordance to IS 2720 (Part 16). This is a widely applied test to assess the properties of highway subgrade as well as to test the performance of materials utilised for sub-base and road base layers. It is very important for empirical design of the pavement thicknesses as well as for quality control during pavement construction. The samples are prepared at OMC obtained from Modified proctor compaction tests. The unsoaked specimens are tested after 2 days of air curing whereas the soaked samples are tested after 4 days of immersion in water.

III. RESULTS AND DISCUSSIONS

3.1 Physical Properties of the Aggregates

The physical properties of the crushed granite and the RA are presented in Table 1. The acceptable limits for the aggregates as specified by MoRD, Government of India, are also included in the table. The MoRD specifications have been referred because the interest is to evaluate the performance of the RA for rural road applications. Nevertheless, the test procedures are the same as specified by MoRT&H.

The results show that the crushed granite tested for this study complied with all the specifications for sub-base and base layers of rural roads. The properties of the crushed granite are found to be better than those of the RA. The RA has lesser specific gravity than the crushed granite, but recorded higher particle losses under impact and abrasion testing. The water absorption of the RA is also higher than the 2 % maximum limit.

Table 1; Physical Properties of the Aggregates

Properties	Test Method	Crushed Granite	RA	Specified Limits by MoRD	
				Sub-base	Base
Specific gravity	IS 2386 (Part III)	2.86	2.38	2.5 – 3.2	2.5 – 3.2
Water Absorption (%)	IS 2386 (Part III)	0.48	3.76	≤ 2	≤ 2
Wet Aggregate Impact Value (%)	IS 5640	20.77	37.16	≤ 50	≤ 40
Loss Angeles Abrasion (%)	IS 2386 (Part IV)	25.12	38.69	-	≤ 40
Flakiness and Elongation (%)	IS 2386 (Part I)	18.20	22.55	≤ 30	≤ 25

The reasons for these inferior quality of the RA include; presence of adhered mortar on the concrete istes, presence of weaker sandcrete particles and brick particles, and also induced internal cracks within the RA particles due to the crushing pressure. Apart from the water absorption of the RA exceeding the specified limit by almost 88%, which is almost double the specified value, it actually satisfied the specifications for the rest of the properties tested. This shows that, the RA would require a high OMC than crushed granite for satisfactory performance in sub-base and base layers of rural roads. This emphasises the need for a careful determination of the Optimum Moisture Content (OMC) of the RA before using them for either sub-base or base of rural roads in India. MoRD as well as MoRTH has recommended the use of modified proctor compaction tests in accordance with IS 2720 (Part VII) method for this purpose. In

Published by: The Mattingley Publishing Co., Inc.

January - February 2020
ISSN: 0193-4120 Page No. 16465 - 16472

addition, MoRD also specified different categories of grading with which a sub-base and base material must comply. The gradation and the compaction properties of the aggregates utilised for this study are discussed in the following sections.

3.2 Gradation of the Aggregates

Particle size distribution is conducted on the crushed granite as well as the RA. The crushed granite and RA are also blended in different percentages, increasing the proportion of RA by 25% at each time. Fig. 2 shows the particle size distribution curves for the crushes granite, RA, and the blended aggregates which are actually utilised for the laboratory experiments.

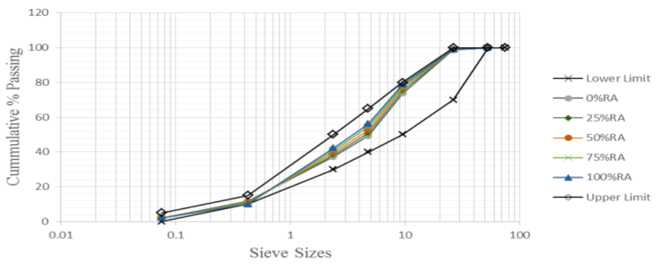

Fig 2. The Particle Size Distribution Curves for the Aggregates

The gradations presented in the table falls within the upper and lower limits specified by MoRD for sub-base and base layers. The aggregates can be classified as GM based on the MoRD soil classification system. This comprises of a non-plastic gravelly moorum soils with appreciable proportions of fines. This is very suitable for rural road construction in India.

3.3 Compaction of the Aggregates

Compaction is a technique of increasing the density of aggregates in order to improve their engineering performance. The ability of a soil to be sufficiently densified at the application of compaction loading is dependent on the loading energy and the moisture content of the aggregates (Nwakaire et al., 2015). Different compaction methods can be utilised to estimate the OMC and MDD of the aggregates, but the modified Proctor compaction method recommended for Indian rural roads by MoRD and MoRTH is adopted in this study. Fig. 3 shows the compaction curves of the various replacement levels of the crushed granite with the RA.

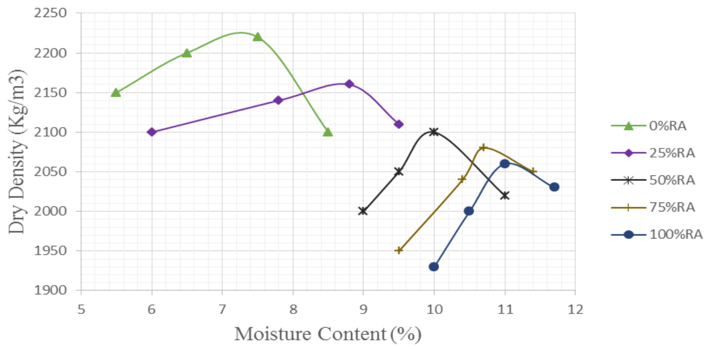

Fig. 3 Compaction Curves for the Aggregates

The figure shows a consistent drop in the MDD of the aggregates with increase in RA content. The crushed granite exhibited the highest MDD while the 100% RA had the least MDD. The result also confirms that as the proportion of the RA increases in the blend, the OMC also increases. A similar observation has been made by researchers from different parts of the world (Xuan et al., 2012; Aginam et al., 2015). The values of these variations in MDD and OMC are plotted in Fig. 4. The values ranges from 2060 kg/m3 to 2225 kg/m3 and 7.3% to 11% for MDD and OMC respectively. The use of 100%RA would result in 7% reduction in MDD with a 50% increase in OMC. The values for 25%RA, 50%RA, and 75%RA fall within this range. The CBR tests are conducted at these OMCs.

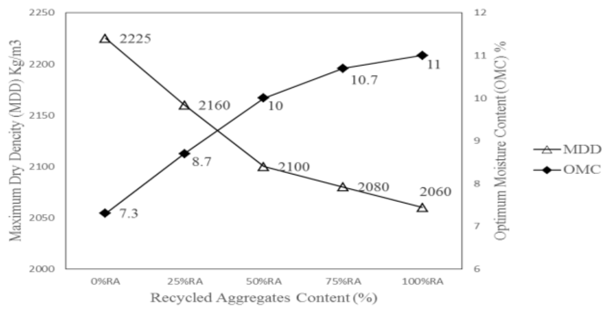

Fig. 4 Variations in Maximum Dry Densities and Optimum Moisture Contents

Published by: The Mattingley Publishing Co., Inc.

January - February 2020
ISSN: 0193-4120 Page No. 16465 - 16472

3.4 California Bearing Ratio

This test is a very important indicator to the mechanical behaviour of the aggregates for road pavement applications. It is specifically utilised to access the performance of road construction materials in India and many other parts of the world. The result of the CBR tests are presented in Fig 5.

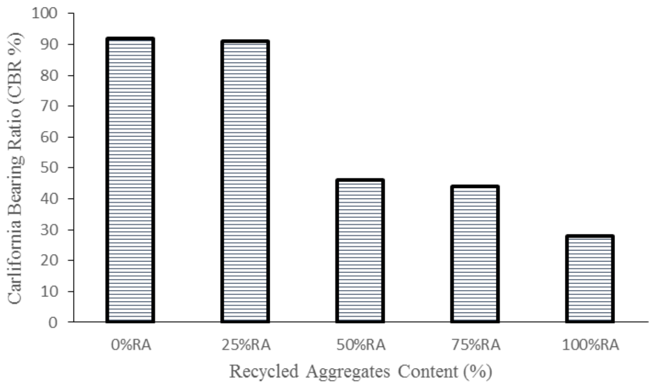

Fig. 5 Result of CBR Test

As observed for the MDD, the CBR also reduced with increasing proportions of RA. The 0%RA, 25%RA, 50%RA, 75%RA, and 100%RA had CBRs of 92%, 91%, 46%, 44%, and 28% respectively. This shows that with 25% RA included in the mix would perform similar to the natural crushed granite with respect to CBR. The values for 50%RA and 75%RA are very comparable but with 50% and 50% reductions, respectively. The 100%RA exhibited the poorest performance, with approximately 70% lesser CBR value than the crushed granite. MoRTHspecified a minimum CBR of 30% for sub-base materials but MoRD specified that 20% is acceptable for rural roads. With respect to MoRD specifications, all the samples achieved satisfactory CBR for sub-base applications of rural roads. Apart from the 100%RA with CBR less than 30%, the RA blends with crushed granite also satisfied the MoRTH specifications for highway sub-base materials. Both codes did not specify any CBR limit for base materials, but for the purpose of this study, the 25%RA with CBR above 80% is recommendable for base layers of rural roads in India.

3.5 Effect of Maximum Dry Density on CBR of Recycled aggregates

This section buttresses further the observed variations in MDD and CBR with varying proportions of RA. Fig. 6 shows the plot of CBR verses MDD which depicts an increase in both CBR and MDD as RA reduced from 100% to 0%.

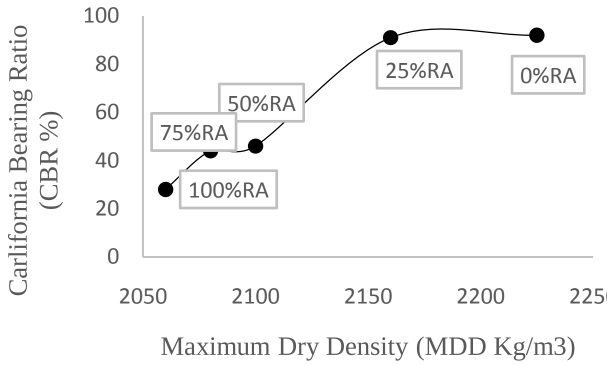

Fig. 6 Increase in CBR with Increase in Maximum Dry Density

A linear Model is proposed to mathematically explain the relationship between the CBR and MDD of the aggregates. The model plot and the mathematical expression if presented in Fig. 7. The model depicts a strong linear relationship between CBR and MDD of the aggregates with R2 value of 0.88.

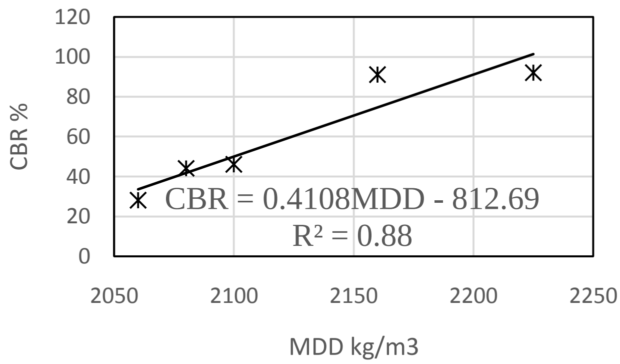

Fig. 7 Linear Model for the relationship of CBR with MDD

The Significant F value is 0.017. The p values for MDD coefficient and the intercept are 0.017 and 0.02 respectively. The model performed well in

Published by: The Mattingley Publishing Co., Inc.

explaining the strong linear correlation between the CBR and MDD. The CBR of the aggregate depends on their MDD. Therefore, the CBR values can be predicted based on the MDD values. Fig. 8 shows the actual and the predicted CBR values of the aggregates.

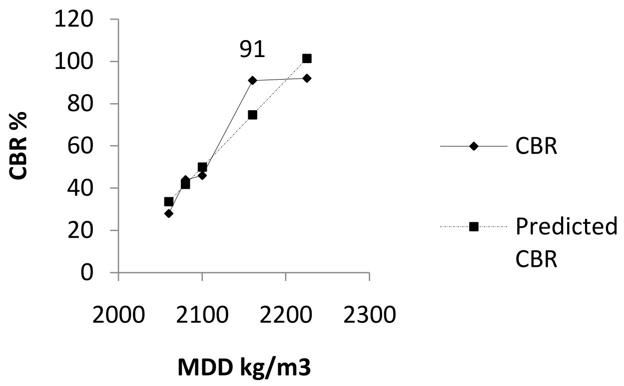

Fig. 8 Actual and predicted CBR values

For the 25%RA, the predicted CBR equals the actual CBR. For the 75%RA, the predicted CBR is less than the actual CBR, and for the 0%RA, 50%RA and 100%RA, the predicted CBR is higher than the actual CBR. These variations are quite minimal as they range from 0 – 18%.

IV. CONCLUSIONS

This study evaluates the performance of RA as Constituents of base and sub base layers of rural roads. The RA utilised for the study is a mixture of different types of demolition iste materials. The aggregates are crushed and blended in different proportions to comply with aggregate grading B for sub-base and base layers. The physical and strength properties of the materials are tested and utilised to evaluate their performance.

It is found that the physical properties of the RA are inferior to those of crushed natural granite. The RA violated the water absorption specifications by MoRD. It exhibited approximately twice the maximum limit for water absorption as specified by MoRD. Besides, apart from the higher water absorption, other physical properties of the RA are within the standard specifications. It is therefore inferred that the RA would require a higher water content at compaction in order to achieve its maximum density and perform satisfactorily.

The MDDs and CBR values of the aggregates reduced with increase in RA content. Based on the CBR values and other tests carried out, it is concluded that utilisation of mixed RA, like the one utilised for this study, is recommendable for rural roads sub-base layers. However, it should be limited to 25% inclusion in base layers for optimal pavement performance.

REFERENCES

[1] Aggarwal Y SiddiqueR(2014). Microstructure and properties of concrete using bottom ash and istefoundrysand as partial replacement of fine aggregates. Const. Build. Mater., 54, pp.210-223

[2] Aginam, C.H., Nwakaire, C., and Nwajuaku, A.I. (2015). Engineering Properties of Lateritic Soils from Anambra-Central-Zone, Nigeria. International Journal of Soft Computing and Engineering 4(6). Pp.

[3] Arulrajah, A., Piratheepan, J., Bo, M., Sivakugan, N. (2012a). Geo-technical characteristics of recycled crushed brick blends for pavement sub-base applications. Can Geo-tech J, 49 (7). pp. 796-811

[4] Azadeganand, O., Yaghoubi, E., Li, J. (2013). Evaluation of the performance of lime and cement treated base layers in unpaved roads. Electron. J. Geo-tech. Eng., 18 (D), pp. 647-660

[5] Cerni, G., Cardone, F., Virgili, A., Camilli, S. (2012). Characterisation of permanent deformation behaviour of un-bound granular materials under repeated tri-axial loading. Constr. Build. Mater., 28, pp. 79-87

[6] Gilpin, R., Robinson, J., David, W.M., Helen, H. (2004). Recycling of construction debris as aggregate in the Mid-Atlantic

Region USA. ResourConservRecycl, 42 (2004), pp. 275-294
[7] Jiménez, J., Ayuso, J., Agrela, F. (2012a). Use of mixed recycled aggregates with a low embodied energy from non-selected CDW in unpaved rural roads. Constr Build Mater, 34, pp. 34-43
[8] Jimenez, J.R.,Ayuso, J.,Agrela, F., Lopez, M. (2012b). Utilization of unbound recycled aggregates from selected CDW in unpaved rural roads. ResourConservRecycl, 58, pp. 88-97
[9] Khabiri, M.M., Saberian, M., Rahgozar, M.A. (2016). Interaction of sub-grade resistance and dimensions of asphalt pavement surface cracks on propagation of secondary distresses. Int. J. Integrated Eng., 8 (3)
[10] Nwakaire, C.M., Nwaiwu, C.M.O., Aginam, C.H. (2015). Equivalent Blows Approach to the Calibration of a Minicompactor for Laboratory Use. Civil and Environmental Research 7(8) pp. 67 – 74.
[11] Vali, R., Saberian, M., Li, J., Shams, G., Van Gelder, P.H.J. (2017). Properties of geogrid-reinforced-marine-slope due to the ground water level changes. Mar. Geo-resour. Geo-technol, pp. 1-14
[12] Vegas, I., Ibaez, J.A., Lisbona, J., Faras, M. (2011). Pre-normative research on the use of mixed recycled aggregates in unbound road sections. Constr Build Mater, 25 (2011), pp. 2674-2682
[13] Xuan, D.X., Houben, L.J., Molenaar, A.A.A., Shui, Z.H. (2012). Mechanical properties of cement-treated aggregate material – a review. Mater Des, 33, pp. 496-502