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Research Article

Performance Evaluation of Hot Mix Asphalt using Recycled Aggregates and Polymer Modified Bitumen

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Abstract: The construction debris generated as a result of demolition of buildings produces a very ill effect on the esthetics of the surroundings. Instead of dumping this waste material if it could be put into some beneficial use this might add to the convenience of the municipality and can be regarded as a step towards the reduction of environmental hazard. This study aims at the utilization of this recycled aggregate for hot mix asphalt in combination with polymer modified bitumen. Several samples were prepared and tested containing 25%, 50% and 75% recycled aggregate along with virgin aggregate. They were compared with a control sample having 100% virgin aggregate. It was found that stability reduced with the increase in percentage of recycled aggregate similarly the percent air voids and VFA (voids filled with mineral aggregates) also increased but remained well above the minimum requirements mentioned in the AASHTO guidelines. The results indicated the suitability of recycled aggregates for the construction of new roads as they were fulfilling all the requirements of a suitable material to be utilized in the construction of pavements.

Keywords: Recycled aggregates, Performance, Marshal Stability, Virgin aggregates, Hot Mix Asphalt

1. INTRODUCTION

The rapid growth of world population has led to an increased demand on the civil engineering industry for development of infrastructure to cater for the growing population. Significant increase in civil engineering infrastructure in both the developing and developed countries has been observed in the first two decades of the 21st century. With the fast-paced development of infrastructure, the natural resources consumed in the construction industry, being a finite entity, have been depleted at an alarming rate. It is estimated that in USA alone, around 200 metric ton of aggregate is recycled annually. Pakistan has seen a dramatic development of the infrastructure in the past twenty years too, with the construction of motorways, dual carriageways and private housing schemes, to name a few. This has had a severe impact on the natural resources of Pakistan, a glaring example of the natural resource depletion being the rapid disappearance of hills supplying the iconic Margalla aggregate. Moreover, the disposal of construction debris has been proving to be a major challenge to city planners. As a natural consequence, it is imperative to explore alternatives in order to increase sustainability of the natural resources. Recycled Aggregates (RCA) has been one of such efforts, with aggregates obtained from demolition of infrastructure components such as roads, bridge and buildings, processed as a waste, re-crushed, graded and reused. This consequently increases sustainability of the natural resources.

The use of recycled aggregates entails systematic assessment of their engineering properties in order to ascertain their suitability for use in the construction industry. Several excellent studies were carried out to study the behavior of recycled aggregates when used in the matrix of concrete and asphalt. In a study conducted in Chicago, USA, Recycled Aggregate (RCA) accrued from demolished concrete structures was used with sand and dolomites in concrete. Concrete samples were prepared with varying water to cement and aggregate to cement ratios. The study concluded that recycled aggregate can be used as a substitute of natural aggregate (NA) with a blend of 75% RCA and 25% NA giving the most viable mix in terms of

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strength [1]. Another study focusing on sustainable asphalt highways concluded that the use of RCA in concrete resulted in compressive strength similar to NA-based concrete. With studies establishing the adequacy of use of RCA in concrete structures, another possible use of RCA was in roads [2].

The mechanical properties of HMA prepared with Recycled Building Material were studied for light volume of traffic. RCA was substituted for Michigan trap rock virgin aggregate. The samples were prepared using HMA mixes with 25%, 35%, 50% and 75% replacement of natural aggregate with recycled building material. The field performance was assessed by determining various parameters like tensile strength ratio (TSR), dynamic modulus (Es), resilient modulus and construction energy index (CEI). The rutting potential was determined using Asphalt Pavement Analyzer (APA). The results showed that the mixes were good for rutting potential of 8mm. The dynamic stiffness was found to be less than the control sample and reduced with the increase in the percentage of RCA. In case of tensile strength ratio, only the mix with 75% replacement of NA with RBM failed to fulfill the specification. The compaction energy was reduced by RCA in HMA and it was recommended that some amount of RCA in HMA mix is allowed to be used [3]. The wastes obtained from demolition of buildings when mixed with hot mix asphalt with percentages of 40% and 30% having sizes of 3/4 inch and 3/8 inch respectively, satisfied all the requirements and specifications of local buildings. It shows satisfactory results when subjected to several tests like marshal stability, immersion compression test, loss of stability test and wheel tracking test [4]. The Reclaimed building material (RBM) in combination with waste concrete, tile and brick when mixed with HMA, produces significant effect on permanent deformation regardless of the temperature and the type of binder used. This mixture also gives satisfactory results in case of stripping value test. The resilient modulus, however, depends entirely upon the testing temperature [5].

Many other waste materials like glass wastes have also been combined with HMA in the proportions of 5%, 10% and 15% and tested for marshal stability, skid resistance, dry/wet moisture damage, water permeability and compaction. It was concluded that glass waste can be conveniently used with HMA in pavement construction without any compromise on economy and engineering properties [6]. This research work also provides an encouragement for using waste material in HMA. The cracking potential can be reduced by reinforcing HMA with waste tire thread mesh which results in increase in the service life and lessens the maintenance and rehabilitation cost of pavements [7].

The overloading of trucks and increase in the number of commercial vehicles are responsible for frequent failure of flexible pavements. At the same time, there is a significant variation in seasonal temperature of the pavements which contributes to distresses in pavements. The conventional bitumen mixes are unable to develop sufficient strength that can sustain the effects of repeated wheel loads. Several studies have been conducted to study polymer modified bitumen (PMB), which is obtained by the addition of polymers into conventional bitumen, for improving its properties like grade, softening point and marshal stability. Performance of asphalt is affected to a large extent by the quality of bitumen. The capability of bitumen can be enhanced by adding polymers like Styrene Butadiene Styrene and linear low-density Polyethylene [8]. After the rheological analysis was carried out for the modified binders with the help of dynamic shear rheometer, it was found that polymer modified bitumen has high resistance to permanent deformation [9].

It is concluded that the use of PMB in bituminous mix with recycled aggregate instead of virgin aggregate will have no negative impact on the performance of pavement hence the use of these materials is fully justified in the light of the previously published work.

2. MATERIALS AND METHODS

TThe recycled aggregate required for this study was fetched from a site situated in district Bannu (KP). It was a building 30 to 31 years old having an abundant amount of aggregates generated as a result of its demolition. In order to judge the quality of these aggregates, they were subjected to the following tests in Highway lab of UET, Bannu Campus. Figure. 1 illustrates the apparatus used for this purpose:

i. Loss Angeles abrasion test was conducted to find its resistance against abrasion according to AASHTO. T. 96.
ii. Specific gravity of the aggregates was found using AASHTO. T. 85.
iii. The capacity of water absorption was determined using AASHTO. T. 85.
iv. Sieve analysis was carried out to grasp information regarding the gradation of aggregates using AASHTO. M. 92

Then the specially recommended polymer modified bitumen was tested as per the standard procedures:

i. Penetration grade of bitumen AASHTO T-49
ii. Softening point of bitumen AASHTO T-89
iii. Flash and fire point AASHTO T-89
iv. Ductility AASHTO T-51

In the next phase of testing the optimum binder content was determined in accordance with ASTMD6927-15. A marshal cake of hot mixed asphalt was prepared by mixing the specified amount of binder with the recycled aggregates.

After that the marshal stability test was conducted on the sample to determine both the stability and flow value for HMA. This procedure was repeated several times by replacing the virgin aggregates with the recycled aggregates by 25%, 50% and 75% respectively. The results were compared with that of the control sample having 100% virgin aggregates.

3. RESULTS AND DISCUSSION

The results obtained by conducting tests on bitumen, aggregates and HMA comprising of virgin and recycled aggregates are tabulated and shown in table 1 and 2. It is quite evident from table 1 and 2 that there is no quality issue with the use of these materials in HMA as all the values lie within the range of the standard mentioned in Table 1. Figure 2 indicates the gradation curve of the aggregates obtained from its sieve analysis which lies in between the upper and lower limits shown by curves.

Fig 1. Snaps from tests conducted on recycled aggregates Courtesy Highway Lab (UET, Bannu Campus)

Table 1. Comparison of results for virgin and recycled aggregates

S.No	Description of tests	Results for virgin aggregates	Results for recycled aggregates	Standards
1	Bulk specific gravity	2.6	2.3	<2.8
2	Water absorption	0.40%	3.4%	<2%
3	Gradation	Class B	Class B	
4	Loss,Angeles,Abrasion	15.4%	23.36%	<40%

Table 2. Test results for polymer modified bitumen

S.No.	Name of test	Result	Range
1	Softening point	57^0C	55-75
2	Flash & Fire point	318^0C	>=235
3	Penetration	52.4mm	25-55
4	Ductility	20cm	>=15

In the next step optimum bitumen content (OBC) was determined for the preparation of Marshal Cake both for virgin aggregates and recycled aggregates respectively as indicated in table. 3 the results are summarized in table. 4 showing that the value of OBC is 4.48%. This particular value was utilized to perform the marshal stability test for control sample and the results obtained for percentage of voids, voids filled with aggregates(VFA), unit weight and stability were plotted against the bitumen content as shown in figure. 3. The same process was repeated using recycled aggregates and PMB mixed in varying proportions of 25%, 50% and 75% and the results are shown by bars in the combined form in figure. 4. The pattern of variation of stability of marshal cake with replacement of recycled aggregates and PMB is clearly depicted in figure. 5. It is quite obvious that the replacement of 25% recycled aggregates produced almost no effect on the stability of the cake. The values remained closer to that of the control sample. The curve shows a decrease in the stability with the increase in the proportion of recycled aggregates. The minimum value being $829kg/cm^2$. Which is still feasible as the minimum limit is 820 kg/cm^2. Figure. 6 and 7 indicates the considerable increase in percent air voids and voids filled with aggregates with the amount of recycled aggregates have been increased.

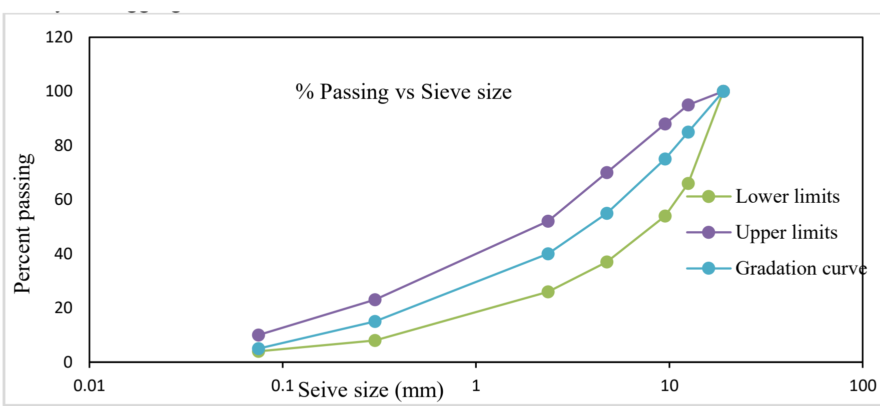

Fig 2. Gradation curve for virgin aggregates

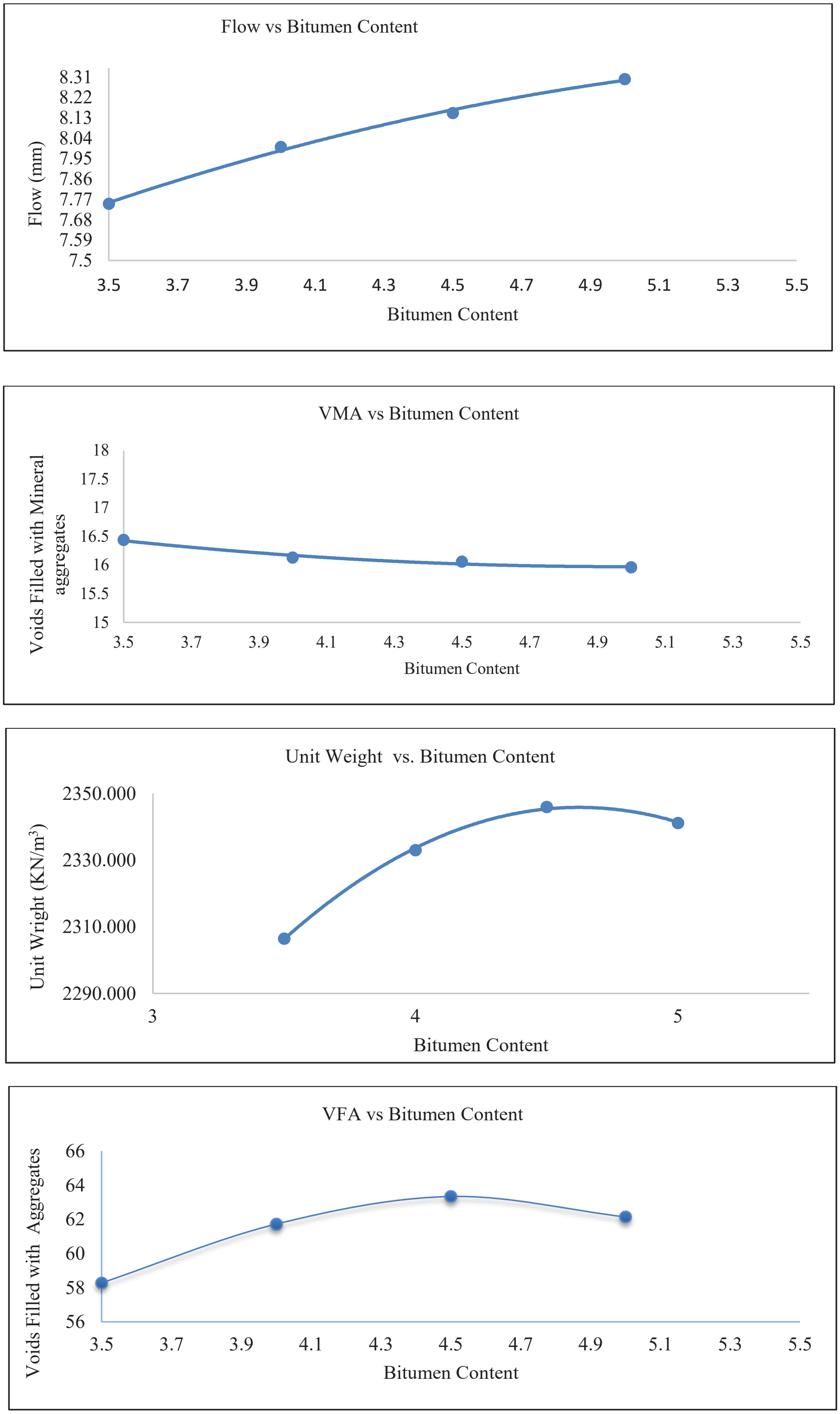

Fig 3. Plots of bitumen content against various parameters for finding Optimum Binder content (OBC)

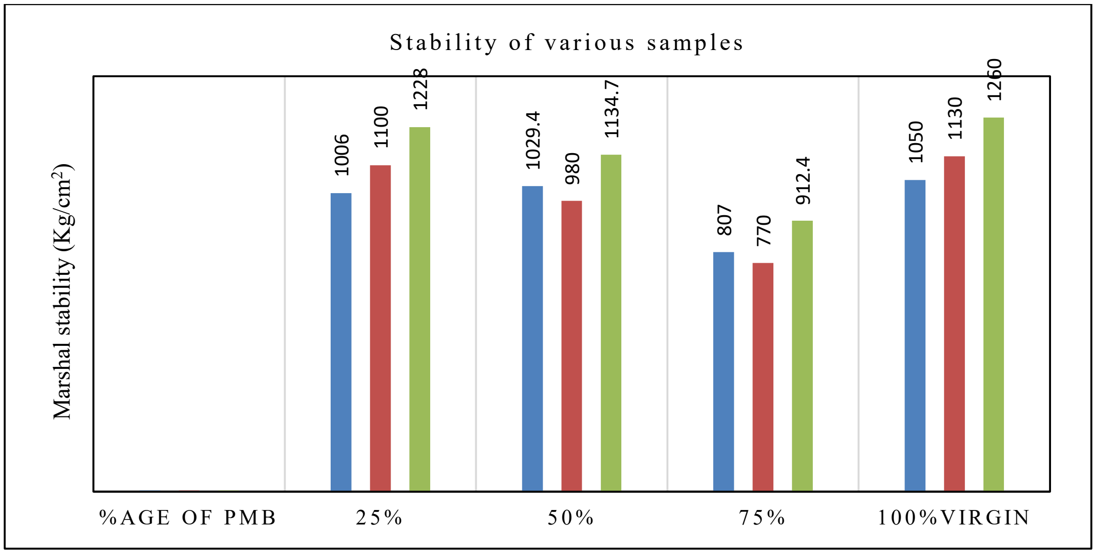

Fig 4. Stability of samples with varying proportions of RCA and PMB

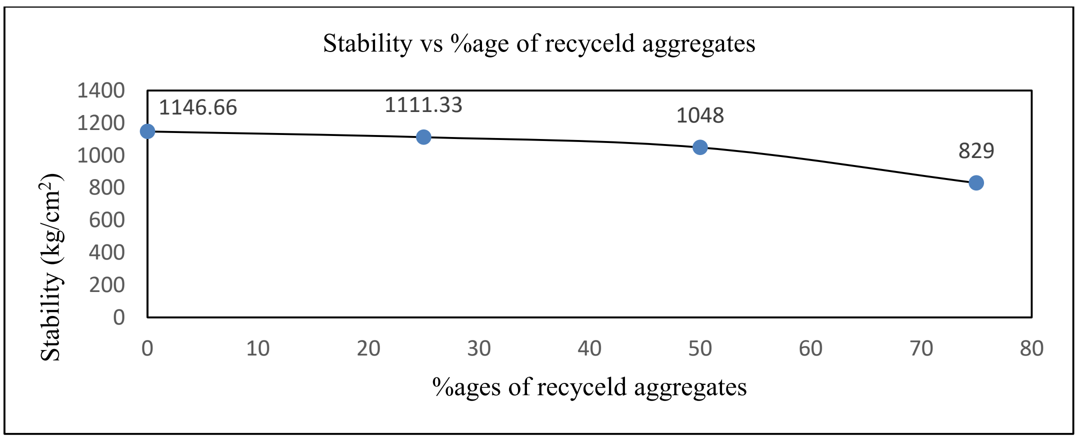

Fig 5. Change in stability with amount of RCA

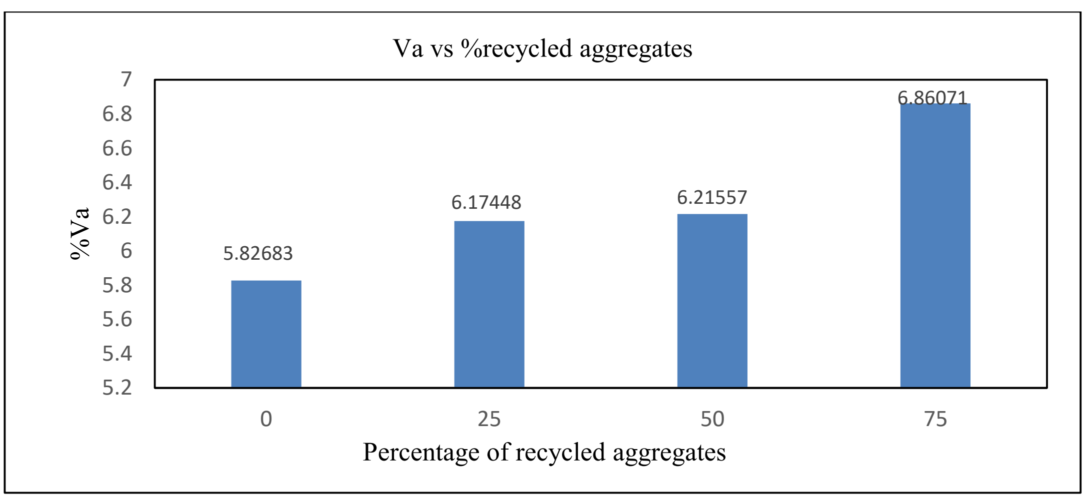

Fig 6. Percentage air Voids with RCA

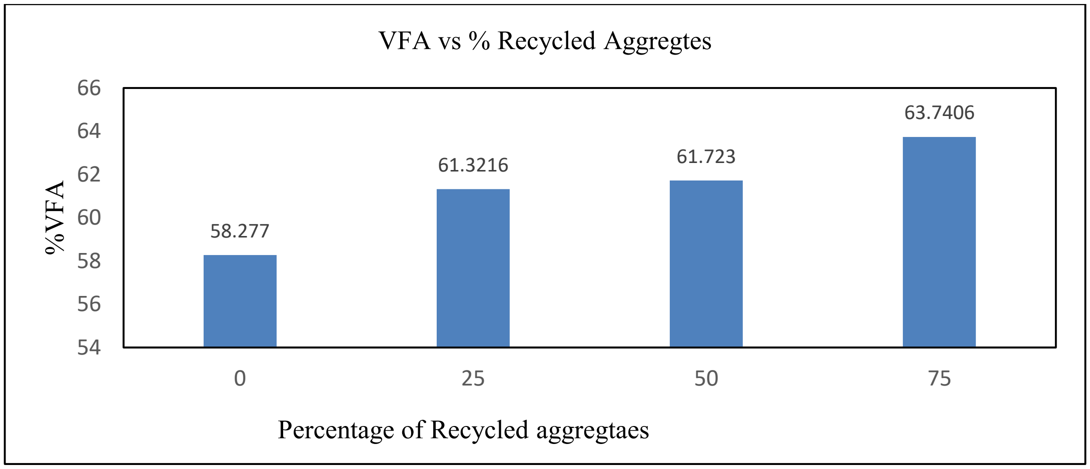

Fig 7. Percentage voids filled with aggregates with RCA

Table 3. Summarized results for OBC

S.No	Description	Bitumen Content(%)
1	Bitumen content at maximum stability	4.50%
2	Bitumen content at 4% air voids	4.20%
3	Bitumen content at maximum unit weight	5.0%
4	Bitumen content at maximum unit weight	4.48%

Table 4. Mix Design for OBC

Sieve size	Percentages	weight for 3.4%	weight for 4%	weight for 4.5%
12.5	17.5	202.65	201.6	200.5
9.5	12.5	144.75	144	143.25
4.75	20	231.6	230.4	229.2
2.36	20	231.6	230.4	229.2
200	20	231.6	230.4	229.2
300	5	57.9	57.6	57.3
Pan	5	57.9	57.6	57.3
Total	**100**	**1158**	**1152**	**1146**

4. CONCLUSIONS

After the careful analysis of the results it can be concluded on firm grounds that recycled aggregates and polymer modified bitumen have got the properties which are acceptable as a construction material for the pavements and its utilization in combination with virgin aggregate in HMA is confirmed.

The proportioning of recycled aggregates with virgin aggregates by 25%, 50% and 75% satisfy all the blending requirements, specified in the guidelines.

The best that can be concluded from this study is that recycled aggregates can be the best choice for constructing new pavements when incorporated in an amount not less than 25% and not more than 75%. The proportions which give the best results based upon stability, stiffness, flow, air voids and bulk density of asphalt are 25% and 50%. Although 75% mix gave less stability but its value is well above the minimum limit which is 820kg/cm^2.

It is recommended that this study must be extended towards the investigation of the resistance offered by the recycled aggregates and polymer modified bitumen in HMA against various distresses of pavements like rutting, cracking and spelling.

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