EFFECTS OF DIFFERENT AGGREGATE GRADATIONS ON RUTTING SUSCEPTIBILITY OF HOT MIX ASPHALT (HMA)

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Abstract- This study focuses on the development of optimum job mix formula (JMF) with lower susceptibility. The effect of change in aggregate gradation in hot mix asphalt (HMA) was investigated for rut depth behaviour in flexible pavement. Samples were prepared at optimum asphalt content (OAC) which was found to be 4% through Marshall Mix Design (MMD). This optimum value was then used to find out the MMD parameters and rut resistance for various gradations. Changes in gradation were done by increasing and decreasing the percentages of coarse and fine particles. The result of this study showed that rut susceptibility increases with the change in coarser or finer aggregate percentage as compared to the control gradation, which is NHA Class A for wearing course. For a constant OAC, the sample with equal amount of coarser and finer particles showed the least rut depth. However samples that showed greater stability experienced higher rut depth which needs to be explored further.

Keywords- Hot Mix Asphalt (HMA), Marshal Mix Design (MMD), Rutting, Wheel Tracking Device (WTD)

1 Introduction

Karachi is the largest city of Pakistan [1] and comes under the category of mega-city [2]. Like other mega-cities, Karachi is also confronting with the situation of increasing population [3]. This population growth results in associated social, economic and business activities [4]. These activities need road infrastructure to meet the growing vehicular demand and fulfilment of related business tasks [5]. Road infrastructure is an important means for mobility of people and goods [6]. All commercial, business, and freight movements are mainly dependent upon it [7]. To meet the mobility demands, a strong road infrastructure is required [8]. It is the case in most developing countries that roads are subjected to higher loading than design [9]. Increase in business activities and population growth along with decrease in strength, invite road distresses. One of the major pavement distress among all is rutting [10]. The attraction towards road transportation has also increased because the railway infrastructure is deteriorating day by day in the study area. Since the last decade road infrastructure has become more than worse when 83% of load shifts to the road from rail along with an 8% annual increment in total traffic volume [11]. This extensive use of roadway causes damage and decrease in its lifespan [12].

The serviceability index is usually used to measure the comfort level provided by the transport facility [13]. Extensive use and misuse of road infrastructure causes damage and increased periodic maintenance [14]. Frequent reconstruction and maintenance activities are affecting the riding quality [15] of travelers as well. This study focuses on finding an optimum gradation and asphalt content (AC) that may help decrease the rutting susceptibility of Hot Mix Asphalt (HMA). Rutting (permanent deformation) of asphalt concrete is considered being a major form of distress [16]. It is characterized by a permanent change in the shape of the pavement or pavement layers due to cyclic wheel loading [17]. It not only affects the service life and performance of the asphalt pavement but also increases vehicle collisions resulting in loss of lives [18]. It will improve the life of the infrastructure with maximum load caring capacity and give a smooth riding surface.

Rutting occurs in the flexible pavement depending on the magnitude of the load and relative strength of the pavement layer [19]. Permanent deformation can occur in the subgrade, the base and the uppermost HMA layer [20]. Rutting in HMA layers is more common in summer [21] as compared to winter, and the pavement deformation is more likely in an aggregate base during the wet spring season [22].

Another factor that causes rutting is stress level which is the function of the magnitude of the load [23]. Application of a heavy load, environmental factors [24] and material quality [12] are some of the major factors that reduce the rutting resistance of pavement. Insufficient initial compaction on HMA, presence of voids, density and bitumen variants are also responsible for the induction of rutting in the HMA layer.

The phenomenon of rutting in the flexible pavement was found in several types of research [16]. Important factors such as the magnitude of traffic loads, loading speed, load repetition, pavement temperature and rutting resistance of asphalt mixture were also being discussed by many of the researchers [25]. Forgiven asphalt pavement material, a deeper rut will develop under heavier traffic loads, lower traffic speed and higher pavement temperature [24]. There are two different mechanisms of rut development. The first one is associated with well-designed structures and stable materials. The permanent deformation is due to the effect of repeated load on pavement materials that are not perfectly elastic. The susceptibility of rutting depends on the stiffness. An increase in the asphalt concrete layer can better this situation [23].

Dramatic increases in the number and weight of vehicles have resulted in severe rutting on highways in Taiwan [26]. The Taiwan Area National Freeway Bureau constructed an in-service test road to investigate the effect of pavement structures and paving materials on pavement performance. A similar study was also conducted by which change in material grade can reduce the rutting effect [27]. Several laboratory tests were also used to study the rutting behaviour such as Wheel tracking device (WTD), Universal Testing Machine, [28] Marshal apparatus [27] and California Bearing ratio and stiffness test [23]. This research focuses on the examination of rutting behaviour of HMA given a constant asphalt content but varying coarse and fine aggregate composition, using laboratory tests such as WTD and Marshal Mix Design.

2 Methodology

Physical and mechanical tests were performed. The result of these tests was compared with the National Highway Authority (NHA) aggregate grading Class A for asphalt concrete wearing course. Properties of mixtures were tested according to MMD. OAC was also determined based on MMD, which was then used for all gradation changes throughout the study. There were four types of gradations. Controlled gradation (CN) is that gradation that is according to NHA Class A [29]. CN gradation has 63% coarse aggregates and 37% fine aggregates. The second gradation developed contained 70% coarse aggregates and 30% fine aggregates. These samples were termed as coarser gradation (C). The third gradation was developed by keeping the percentage of both coarse and fine aggregates to 50%. These samples were termed as finer gradation (F). The last type of gradation was termed coarser finer (CF). CF sample contained 60% coarse aggregates and 40% fine aggregates (Table 1).

Table 1: Aggregates gradation detail

Sieve Size	Gradation			
	NHA "CN"	**Coarse 'C'**	**Finer 'F'**	**Coarser Finer 'CF'**
	Percentage Retained			
	C=63% F=37%	**C=70% F=30%**	**C=50% F=50%**	**C=60% F=40%**
3/4	10%	10%	10%	10%
1/2	0%	20%	10%	10%
3/8	30%	20%	20%	25%
# 4	21%	20%	10%	15%
# 8	13%	5%	20%	15%
#16	21%	20%	25%	20%
# 200	3%	3%	3%	3%
Pan	2%	2%	2%	2%

In the end, all four types of samples were being tested for rutting. Comparison of volumetric properties like stability, flow and density along with rut resistance were be analyzed and compared with NHA specification and international guidelines. Figure 1 will provide the details of the procedure followed throughout the study.

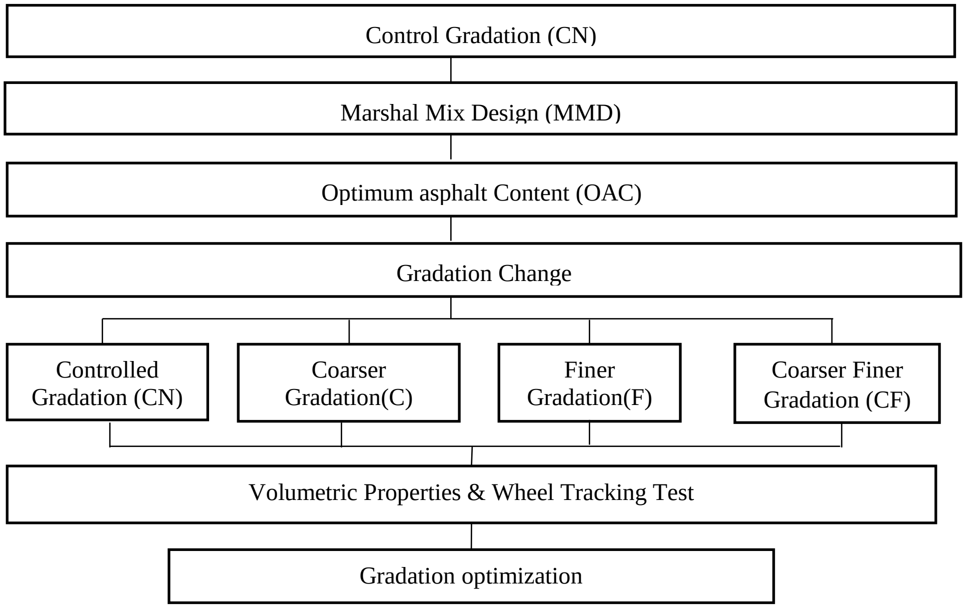

Figure 1: Flow chart of study

2.1 Experimental Program

2.1.1 Aggregates

The mixture of aggregates and asphalt was made up of three types of samples that were used, which were changed concerning their sizes. Mechanical Material properties of materials were not changed. Asphalt was the same throughout this study. Limestone was made available from local material suppliers and consistent throughout. Tests were performed on aggregates following the American Society of Testing and Materials (ASTM) and British Standard (BS). NHA and other international bodies like ASTM and BS Limitations were used for the selection of aggregates (Table 2). Aggregates were sieved and washed as per recommendation before testing as this study used variations in aggregates gradation. This variation is within the NHA gradation Class A.

Table 2: Summary of aggregates properties

Test	**Standard**	**Result**	**Recommendation**
Abrasion Test, (%)	ASTM C131	28.30	< 30
Specific gravity, (-)	ASTM C127	2.67	2.5 - 3.0
Absorption, (%)	ASTM C127	0.71	0.1 - 2.0
Impact value, (%)	BS 812	15.80	20 - 30
Crushing value, (%)	BS 812	20.12	< 30

2.1.2 Asphalt

Asphalt is a cementing material. It was made available from the local market. The following laboratory tests were performed. The results of those tests were being compared with the recommended values. The asphalt used was the requirements of local and international agencies (Table 3).

Table 3: Summary of asphalt testing

Test	Standard	Result	Recommendation
Penetration Grade	ASTM D5	60 - 70	60 – 70
Flash Point, (°C)	ASTM D92	130.0	120 (min)
Fire Point, (°C)	ASTM D92	290	230 (min)
Softening point, (°C)	ASTM D36	51.5	50 – 60
Specific gravity, (-)	ASTM D70	1.02	1.00 – 1.05
Consistency, (sec)	ASTM D139	>1200	1440
Viscosity , (cSt)	ASTM D2171	1323	800 – 1600
Ductility, (cm)	ASTM D113	110	>100

2.2 Test Specimens: Marshall and Rut Test

The volumetric results of mix sample were analysed. Marshal Mix Design was used to determine the properties of the mix. MMD was done for heavy traffic. Seventy-five blows on each side of the samples. Firstly, all the results were derived for CN sample type. OAC was then determined. NHA [29] guidelines provide a specification to have OAC on 4.0 % to 7.0 % air voids for wearing course. 6.0 % Air voids are taken for optimum determination. This OAC were used for all types of a mix; CN, C, F, and CF. Volumetric properties like stability and flow determined for all types of asphalt mix. After comparing mix properties, rut samples were prepared. Three rut samples were tested for each type of mix. A total of nine samples tested for rutting. These results of the rut and volumetric properties were then compared based on the mix type and percentage of aggregates. A typical specimen for rutting weight approximately 11-12 Kg depending upon the optimum density achieved. For each type of rut sample, it varies. The optimum density of each type of mix was different. That is the reason for the weight change of the rut sample for every type of mix. The size of the rut sample [Figure 2] was 300mm by 300mm and was 50mm thick. The rut sample was set for 20 mm maximum rut depth or 5000 load cycles whichever comes earlier. The testing temperature for rutting was 60°C.

Figure 2: Rut samples

3 Results and Discussion

Samples were prepared at different asphalt content using controlled gradation CN. The Asphalt content varies from 3.5% to 6.0% at 0.5% interval. After the analysis of the test result from volumetric analysis. Optimum asphalt content comes out to be 4.0%. This OAC was used to prepare the sample for volumetric assessment with gradation change from coarser to finer. The stability relation with gradation is shown in Figure 3. Stability is highest for CN gradation while lowest for C gradation. On the other hand, CF and the F gradation had lesser Stability than CN. However, all the samples have greater stability than the threshold limit, which is 680.38Kgf [30]. The percentage of air voids have reverse behaviour of stability. The lowest air voids result in the case of CN gradation. While C gradation has the highest percentage of air voids. CF and F gradations have air voids in increasing order, respectively. It was found that a higher percentage of either coarse or fine aggregates lead to a higher percentage of air voids, and the higher the air voids the lower the stability.

Figure 3: Relationship between stability and aggregates gradation type

The result of air voids was found opposite in nature as compared to the earlier result of gradation versus stability, that is, voids ratio increased with an increase in the percentage of same size particles. This concludes that a higher percentage of either coarser or finer particles will lead to a higher number of air voids (Figure 4). The coarser (C) and finer (F) gradations developed were experimental and hence could be the reason behind the anomalous results.

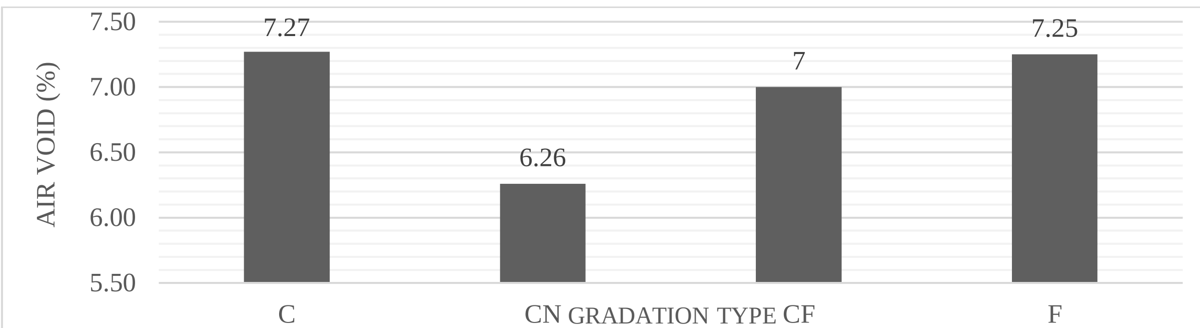

Figure 4: Relationship between air voids percentage and aggregates gradation type

In the gradation change, coarser particles were increased. The increase in the coarser particle ultimately decreases the finer portion. The study only discussed the increase in coarse aggregates. Figure 5 shows that stability increases with the increase in coarse aggregates. It is observed that for all percentages of coarse aggregates value of stability is within the range provided by the authorities [29]. A lesser percentage of coarse aggregates produced lesser stability same is the case for a higher percentage of coarse aggregates. The maximum stability values were obtained at the average region coarse aggregate gradation, the minimum percentage for coarse aggregates was 50% while the maximum was 70%.

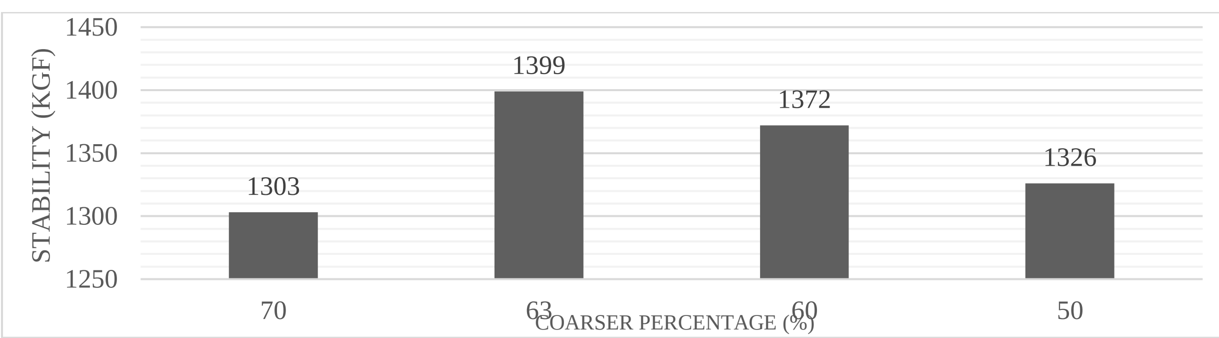

Figure 5: Relationship between stability and percentage of coarser particle

Rut test was performed through Wheel Tracking Device and the results are presented in Figure 6. The weight of material for the rut sample was calculated through optimum density. Optimum density was observed by MMD at OAC. Rut test was performed on every gradation type with replication of three samples. A total of 12 samples were tested. The performance of the gradation type was analysed. Gradation F has higher resistance for rutting. Gradation C and CF has also shown good result. Although, CF has better resistance than C. Gradation CN crosses the limits of the rut for wearing course [30]. This is a very important finding which concludes that CN gradation type, that is NHA gradation Class A is comparatively more susceptible to rutting then gradations having more finer aggregates.

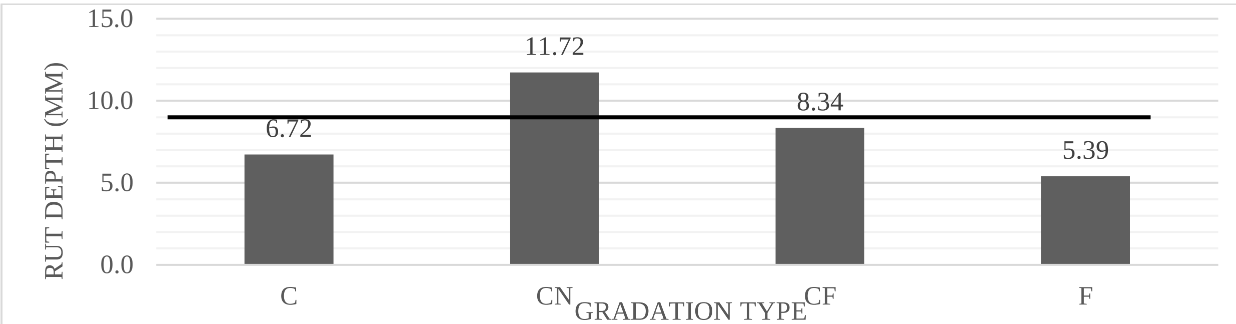

Figure 6: Relationship between rut depth and gradation types

The two extremes of coarse gradation percentage showed lesser susceptibility against rutting. It was found that finer (F) gradation produces the highest rut resistance, while 60% to 64% of coarse aggregates in the mix lead to lesser rutting resistance. This indicates that the behaviour of samples on Wheel Tracking Device is anomalous and does not conform to the usual understanding of the trend pertaining to physical parameters of HMA.

4 Conclusions and Recommendations

The study concludes that the lower the air voids percentage the higher the stability. As CN gradation has the lowest air voids percentage, it has the highest stability. Comparatively C gradation has vice versa. Stability values were within the limits for every type of gradation. The stability of NHA Class A gradation for wearing coarse, which is sample CN, was found to have the highest stability and lowest air voids. However for the same OAC the results were different for rut test. Rutting susceptibility is directly influenced by the gradation of aggregates. The sample with equal amount of coarse and fine aggregates, that is F gradation, showed least rut depth than other gradation types. Comparatively the CN sample showed highest rut depth. An OAC of 4% may have led to bleeding of asphalt in this sample and could be the possible reason behind a higher rut depth. These results lead to the conclusion that rutting susceptibility is influenced by the gradation of aggregates however OAC needs to be evaluated for each gradation type. Determination of Optimum Asphalt Content (OAC) plays an important role in determining rutting susceptibility and hence needs to be further explored. This study only focuses on OAC determined by MMD for the controlled sample, and then employed to all gradation types which led to higher rut depths for samples that showed better stability for MMD.

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