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Rutting in Asphalt flexible pavement

Abstract:

This article describes and analyses the rutting forming process, basic classification, and control standard of the rutting depth, and the results show that, understanding of the fundamental characteristics of the rut and mastering of the rut control standards, is an important reference index which is used to design the asphalt pavement structure and materials.

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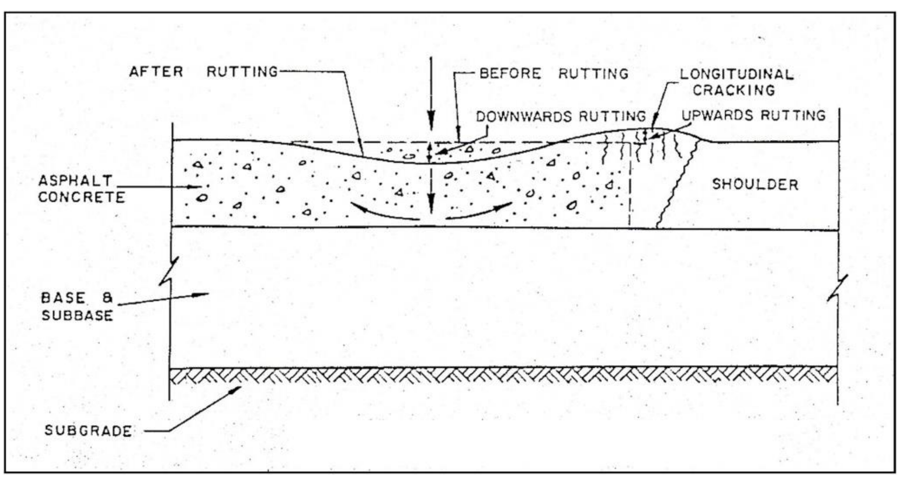
Introduction of rutting asphalt:

A rut is a permanent, longitudinal surface depression that occurs in the wheel paths of a flexible asphalt road surface due to the passage of traffic. Ruts accumulate incrementally: every time a heavy vehicle passes a small, permanent deformation or consolidation is caused. Further into the lifespan of the pavement, the surface deformation may be accompanied by heave, along each side of the rut.

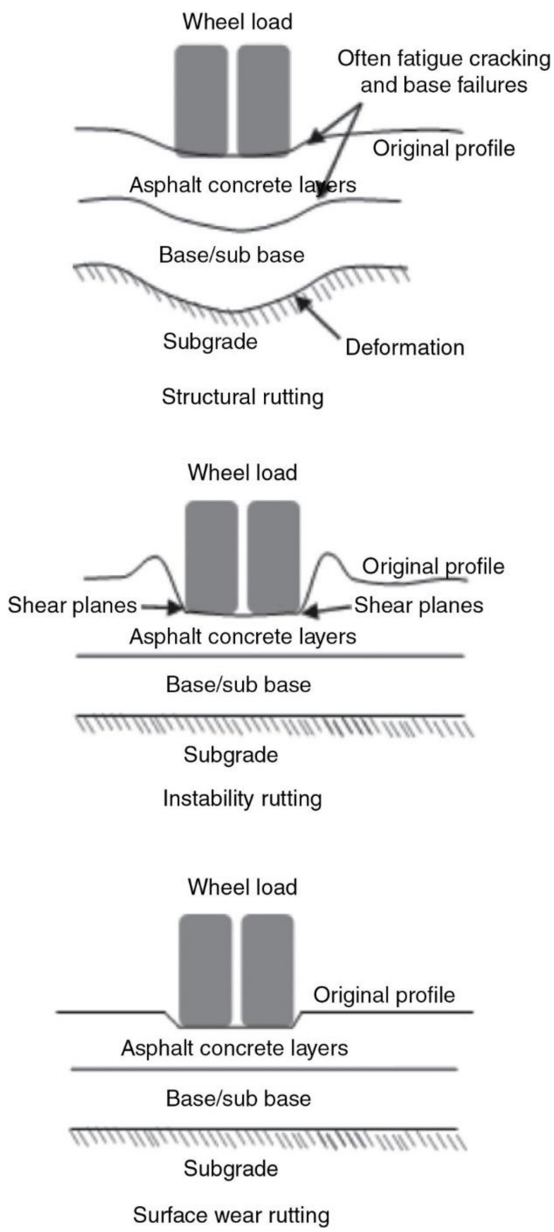
The function of pavement is to carry traffic safely, smoothly, and economically from one location to another. However, various factors such as material properties, construction quality control, traffic loading, and the environment collectively act over time to reduce the original smoothness of the pavement. In flexible pavements, this reduction in pavement smoothness or serviceability will ultimately lead to failure or an intolerable level of roughness. The most common forms of load associated distresses leading to a reduction in serviceability of flexible pavements are permanent deformation (rutting) and fatigue cracking. According to the AASHTO design equation for flexible pavements, a 1.1 in rut depth will reduce the present serviceability index (PSI) of relatively new pavement, having no other distress, from 4.2 to 2.5

Rutting in flexible pavements develops gradually with an increase in the number of load applications, typically manifesting as longitudinal depressions in the wheel paths and minor upheavals to the sides, as seen in Figure 1



Types of rutting:

There are three basic types of asphalt pavement rutting: surface wear rutting, structural rutting and in-stability rutting. The types of asphalt pavement rutting are shown in Figure 3. The factors that influence the pavement rutting performance can be categorized into three groups: material properties, such as property of bitumen, binder content, aggregate property, etc.; climatic and traffic; and construction quality.



Some studies demonstrate that the design of the aggregate gradations with the maximum aggregate size is considered to be resistant to rutting. However, the aggregate gradations need to satisfy the one aggregate filling the voids of the coarse aggregate, as well as the choice of maximum aggregate size of the coarse aggregate which depends on the thickness of the asphalt concrete layer and the current asphalt design standards. Therefore, the study of aggregate composition and considering the effect of maximum aggregate size on rutting is necessary. This paper presents the results of initial research in the laboratory about the effect of aggregate gradation on the rutting resistance.

it was often erroneously blamed on surface instability. Investigations at the AASHO road test in 1959, however, revealed that permanent deformation occurred in all layers of the pavement system, as illustrated in Figure 2. From 51 sections trenched in 1960, the total permanent deformation was distributed among the component layers in the following average proportions [6]:

Component layer	Percentage of permanent deformation
AC surface	32
Base	14
Subbase	45
Subgrade	9

Other studies have indicated that as much as 19% of the permanent deformation may be attributed to the subgrade, while others have shown that for 6 in thick bituminous pavements, rutting was entirely due to deformation within the asphalt concrete.

Causes of rutting:

It is caused by a combination of densification (decrease in volume and, hence, increase in density) and shear deformation and can occur in any one or more of the pavement layers as well as in the subgrade. Although the rutting problem must be addressed for structural and economic reasons, the concern for permanent deformation may also be related to traffic safety. Pavement rutting can cause operating hazards such as loss of vehicle control during lane changes and hydroplaning due to the accumulation of water in the wheel path.

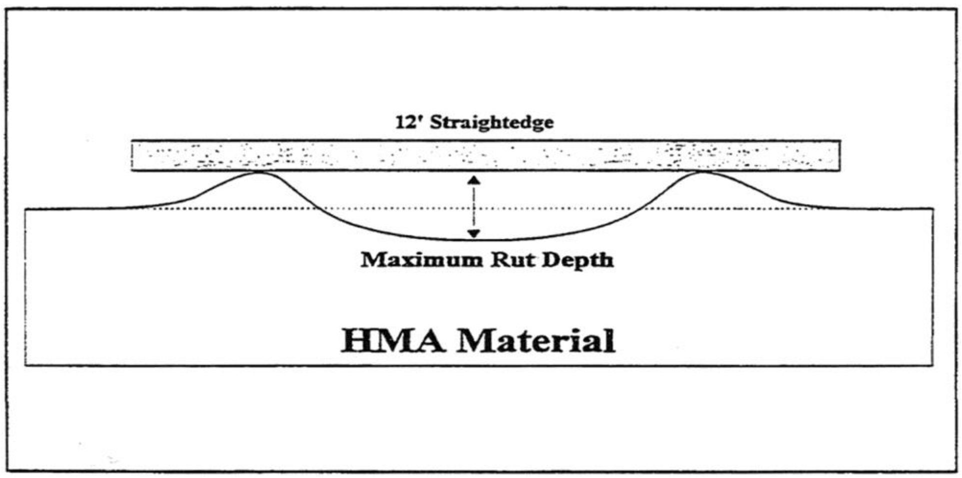
In Iraq, within about 1 year after construction, rutting distress was observed at several locations on the highways due to the high axle loading coupled with the relentless high summer temperatures [3]. For instance, in Baghdad city (the capital of Iraq) the ambient air temperature for nearly 3 months can reach 50°C (and pavement surface temperature can reach up to 60°C), which enhances the rutting problem in local roads.

Traditionally, flexible pavement design considers the permanent deformation problem indirectly using the maximum level of rutting allowed for the entire pavement structure. This is made based on the assumption of the allowable magnitude of compressive strain at the top of the subgrade rather than predicting its actual magnitude within the pavement layers. In order to achieve a reliable estimate of the pavement rutting, one must consider loading, material, and environmental variables when developing the law at which permanent deformation accumulates to ascertain pavement layer on the basis of laboratory works. One of the basic requirements for this law is to test the material in the lab under conditions that satisfactorily simulate the field conditions. Although, the characterization of a material's permanent deformation potential in the laboratory under repeated loads is central to its contribution in rutting appearing at the surface of the pavement structure, the variability in the traffic as well as the environmental conditions in the field make their simulation in the laboratory somewhat difficult.

Although there is an agreement among the researchers that the rutting in asphalt concrete pavement is a major distress type, so far most of the previous research focused on one of the following: (1) single aspect or synergic effect of some contributory factors that cause rutting, (2) common permanent deformation test methods, and (3) prediction of rutting in asphalt concrete. Therefore, there is a distinct lack of an in-depth review of rutting in asphalt concrete that provides a complete comprehensive understanding for this major distress type. In view of the above preface, this research would serve as a practical guide that could help the pavement construction community by covering the findings of research studies in terms of causes, measurement, both intrinsic and extrinsic affecting factors, material characterization, and test methods, and the prediction methodology for rutting in asphalt concrete pavement.

Rutting measurement and criteria:

Rut depth is defined as the vertical distance between the valley and the crest of the ruts. Rut depth is measured by placing 1.2 m (or 3.6 m) metal straightedge across the wheel path to establish a horizontal reference line and measuring the vertical distance between the straightedge and pavement surface by 0.3 m (12 in) ruler (as shown in Figure 5). This measurement is repeated for each 6 m interval (in traffic direction) in both wheel paths and the results are averaged to give the mean rut depth.



The occurrence of permanent deformation or rutting is one of the major problems affecting the performance of pavement structure. It is considered as a serious safety problem encountered by the vehicles for two reasons:

Loss of vehicle control during lane changing, ruts tend to pull a vehicle toward the rut path as it is steered across the rut.

If the rut depth is greater than 12.5 mm for pavement with crown slopes on the order of 2%, this rut depth is sufficient for the accumulation of water (pounding) and possibly causing vehicles traveling at a speed of 80 km/h or more to hydroplane.

Based on the AASHTO guide, rutting is classified according to severity level as exhibited in Table 1

Rut depth criteria according to AASHTO (1993)

Mean rut depth (mm)	Severity level
6–13	Low
13–25	Medium
>25	High

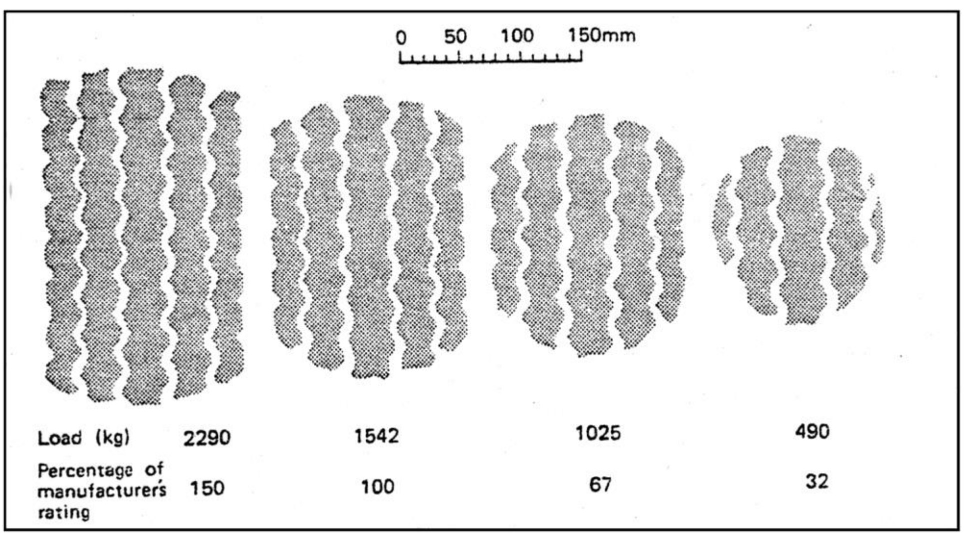
Factors affecting rutting:

The AASHTO Joint Task Force on rutting expressed the opinion that there are many factors that can influence HMA rutting. Traffic and environmental (temperature) factors were identified as the major causes of HMA rutting. Unfortunately, the highway agencies have little control over these two factors. However, there are also important factors that have contributed to the HMA rutting problem that is within the control of highway agencies. Highway engineers have focused attention on these factors rather than the traffic and environment. With proper control of asphalt cement, aggregate quality and gradation, asphalt content, and construction, the HMA rutting problem can be greatly minimized. The subcommittee on materials of the Western Association of Highway and Transportation Officials, WASHTO, has also made recommendations on the selection of materials to minimize the HMA rutting

Traffic characteristics:

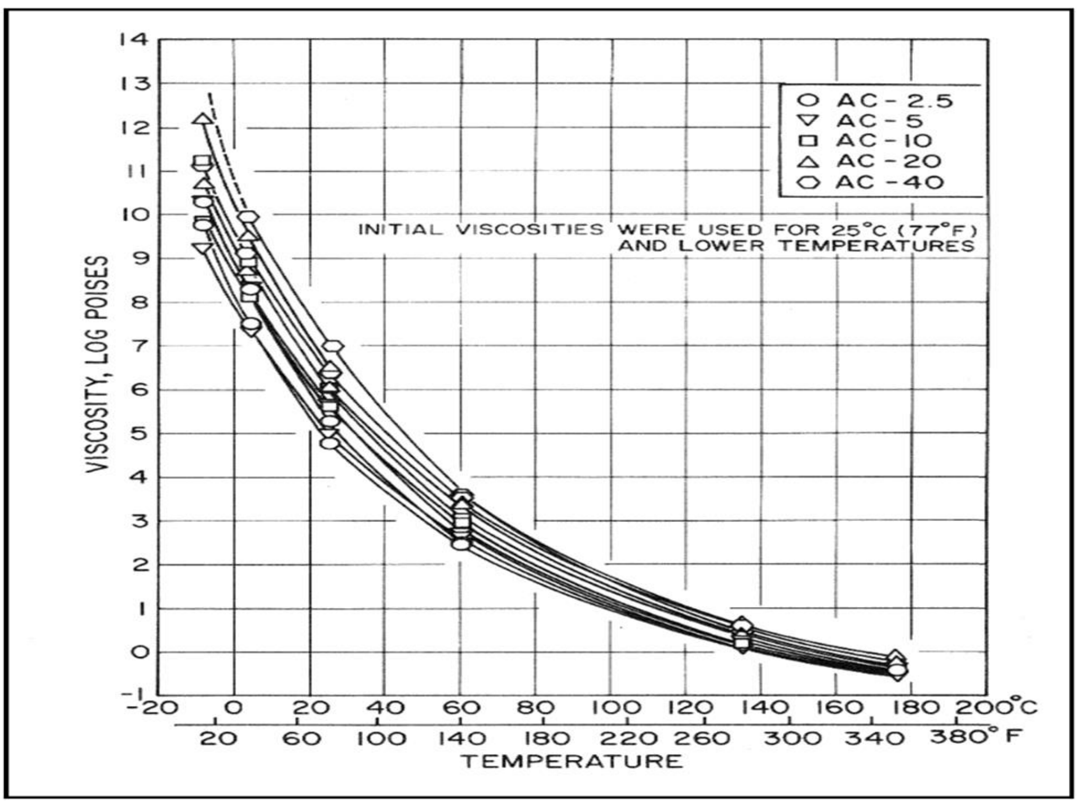
Traffic characteristics is one of the most important factors affecting rutting, it includes tire contact pressure, vehicle speed, and the number of load repetitions (traffic volume).

The shape of the contact area between a tire and the road surface is approximately circular when the load applied is small relative to the recommended maximum for the tire, but it becomes increasingly elongated as the wheel load is increased at constant inflation pressure, this is shown in Figure 6, where the highest load considered is 50% above the tire manufacturer's rating. In calculating pavement stresses resulting from the passage of the traffic, it is usual to assume that the load carried by the wheel is uniformly distributed over a circular area and the radius of loading is calculated from the wheel load and the tire pressure, this is because it is assumed that the tire pressure is equal to the contact pressure (no effect for tire wall).



Temperature:

Rutting is more prevalent in hot climate areas because the viscosity of the asphalt binder which is inversely related to rutting is significantly reduced with the increase in temperature resulting in a more rut susceptible HMA mix. Figure 8 shows the effect of temperature on log asphalt viscosity for a wide range of asphalt cement grades. From the Figure, it is obvious that the viscosity of asphalts varies from less than one Poise to more than one trillion Poises. Within such an extreme viscosity range, asphalts are transformed from low viscosity Newtonian liquids to materials exhibiting shear-dependent visco-elastic behavior, where with decreasing temperature, the elastic component tends to be predominant. Thus, the gradually changing curvature of plots in Figure 8 indicates that the viscosity of asphalt tends to change more rapidly at low temperatures, and such change becomes far less pronounced at higher temperatures when the viscous behavior is predominant.



Minimizing rutting in asphalt:

Valuable and many efforts have been made by researchers in the past years to reduce the rutting mode of distress in asphalt concrete mixtures, and they have varied in nature from controlling the components of the asphalt concrete mixture to the use of additives, as well as the use of new types of sustainable asphalt concrete mixtures. Results of the laboratory investigation conducted by Button et al. showed that the chief mixture deficiencies contributing to rutting were excessive asphalt content, excessive fine aggregate (sand-size particles), and the round shape and smooth texture of the natural (uncrushed) aggregate particles. The researchers suggested increasing voids in mineral aggregate requirements (14–15% minimum), replacing most or all natural sands with manufactured particles, increasing minimum allowable air voids in the laboratory-compacted mix to 4%, and limiting the filler-to-bitumen ratio to about 1.2. On the bases of natural sand, Albayati and Abdulsattar recommended that the highway-specifying agencies should consider limiting the natural (uncrushed) particle content of asphalt mixes in high-volume pavement facilities to about 10–15%, depending on other characteristics of the mixture.

Other researchers focused on the enhancement of the rheological properties of asphalt cement to mitigate the rutting in asphalt concrete since the asphalt binder characteristics account for around 40% of the performance of asphalt pavements with regard to permanent deformation.

Hamid et al. indicated that the addition of 8% glass fiber (GF) to the neat binder enhanced the rutting resistance of the asphalt mixture, which reduced the rut depth by 55%. The combination of the styrene butadiene styrene (SBS) and GF (2% SBS + 8% GF) reduced the rut depth to 82% as compared to the control mix with neat asphalt cement. Other types of polymers were also tried by researchers and show distinct results, Bulatovic et al. used ethylene copolymer. Epoxy resin showed excellent resistance to permanent deformation. High-modulus modifiers exhibited better resistance to rutting as compared to the control mix.

Also, hydrated lime which has been categorized as a major additive in asphalt pavement because of its wide availability and relatively cheap cost, when implemented in a dosage of 2.5% by weight of aggregate has shown premium resistance to rutting. The same additive when used in the nanoscale at a dosage of 1.5% enhanced the resistance for rutting. Other nanomaterials were also tried by researchers and showed promising results. Aljbouri and Albayati investigated the use of nanomaterial, including nano silica (NS), nano carbonate calcium (NCC), nano clay (NC), and nanoplatelet hydroxyapatite (NP), the results revealed that nanomaterials significantly improved the resistance of rutting.

The Enrobes à Module Eleva or simply high-modulus asphalt which was developed in France as a high-performance mixture for use in heavy-duty pavements also exhibits premium resistance to permanent deformation as compared to conventional dense graded asphalt concrete mixture. Also, some studies have shown that stone mastic asphalt (SMA) mixture has high resistance to deformation with high coarse aggregate content interlocked to form a stone skeleton that is more durable and rutting resistant than the conventional asphalt mixtures. Sustainable warm mix asphalt (WMA) is currently gaining popularity due to increasing material prices coupled with more acute environmental awareness and the implementation of regulation which has driven a strong movement toward the adoption of sustainable material. According to many investigations, the permanent deformation resistance of WMA was frequently greater than that of the control HMA mixture due to the lower mixing temperature and shorter binder aging times. The improvement in the rutting resistance of WMA was influenced by the type of warm additive, mixes having additives such as Asphamin® and Evotherm® revealed comparable rutting resistance to the control mixture.

Conclusion:

Rutting in asphalt concrete occurs in one of the following types: wear rutting which is due to the progressive loss of coated aggregate particles from the pavement surface, structural rutting due to permanent deformation in the subgrade, and instability rutting in asphalt concrete layers. The mechanism of instability rutting is the densification (decrease in volume and, hence, increase in density) and lateral displacement (shear deformation) of material within the pavement asphaltic concrete layers. According to the AASHTO guide [17], rutting is classified based on the severity level to low (6–13 mm), medium (13–25 mm), and high (more than 25 mm). The increased tire inflation pressure has placed the HMA mixture near the surface under high stresses, through increase in the probability of rutting. Rutting is more prevalent in hot climate areas because the viscosity of the asphalt binder which is inversely related to rutting is significantly reduced with the increase in temperature, the rut depth increases by a factor of 250 when the temperature increases from 20 to 60°C (from 68 to 140°F). Asphalt concrete mixture components, asphalt cement, aggregate quality and gradation, and asphalt content have a great effect on HMA rutting problem. The laboratory tests usually used to characterize the permanent deformation response of asphalt concrete are typically categorized as uniaxial, triaxial, or diametral, within those three general categories loading may be static (creep), repeated, or dynamic. Also, the wheel track test is usually used to evaluate the rut depth in asphalt concrete mixtures, this type of test is gaining popularity as it is best to simulate the traffic condition.

Many efforts have been made to employ a variety of methodologies to create a rutting prediction model that takes into account a variety of effective factors. Mainly, a power permanent strain low showed a promising result when employed in the framework of elastic layer-strain procedure. Also, another approach makes use of closed-form viscoelastic analyses to represent pavement structure with permanent deformation characterization by means of creep test. A computer program, for instance, VESYS, also could be served as a good tool to predict rut depth using the elastic layered-strain procedure and the asphalt concrete characterized by Alpha and Mu. Recently, Artificial Neural Network Approach is used to predict the rutting in asphalt concrete mixtures.

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