Accelerated Pavement Testing Used for the Rutting Model Calibration of Korean Mechanistic-Empirical Pavement Design Guide

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ABSTRACT: Development of failure models for asphalt pavement has been carried out continuously throughout the world including AASHTO since 1960’s. And most of the failure models for asphalt pavement employed regression analysis of numerous test data up until 1980’s. However, these experiential methods have limitations in not being able to consider material characteristics, actual condition in the construction field site, etc.Thus, several countries including the USA are now interested in the mechanistic-empirical pavement design method in order to deal with these problems. Likewise, Korea has shifted its focus on empirical-method of pavement design to the mechanistic-empirical pavement design method as Korean-pavement design methods have progressed. The pavement design for rutting of asphalt concrete pavement among the developments of Korean- pavement design methods involves identification of rutting characteristics appropriate for asphalt admixtures so that a rutting model can be developed by the combination of dynamic and experiential pavement design method. This study conducted an Accelerated Pavement Testing (APT) of a performance-based prediction model in terms of rutting of asphalt pavements. This test identified the materials necessary for the development of rutting model of HMA at 50℃ temperature in order to collect the basic data for the rutting model. Data of rutting and resilient deflection (e.g., plastic strain, ϵ_p, and resilient strain, ϵ_r) were collected for the development of HMA (e.g., AP-5, 19mm dense grade) course in this study.

KEY WORDS: Accelerated pavement testing, rutting model, plastic strain, resilient strain

1 INTRODUCTION

Development of failure models for asphalt pavement has been carried out continuously throughout the world including AASHTO since 1960’s. And most of the failure models for asphalt pavement employed regression analysis of numerous test data up until 1980’s. However, these experiential methods have limitations in not being able to consider material characteristics, actual condition in the construction field site, etc. Thus, several countries including the USA and European countries are now interested in the combination of mechanistic-empirical pavement design methods in order to deal with these problems. Likewise, Korea has shifted its focus on empirical-method of pavement design to the mechanistic-empirical pavement design method as Korean-style pavement design methods have progressed. The pavement design for rutting of asphalt among the developments of Korean-pavement design methods involves identification of rutting characteristics appropriate for asphalt pavements so that a rutting model can be developed by the mechanistic-empirical pavement design method. This study conducted an Accelerated Pavement Testing (APT) of a performance prediction model in terms of rutting of asphalt pavement.

APT is used for the purpose of obtaining the data for the verification of mechanistic-model and performance of pavement by installing a pavement test specimen inside APT laboratory so that the pavement can be tested against the loading of vehicles and environment in an accelerated pace. The typical cross-sectional of Korean expressway pavement consisting of asphalt layer of 30 cm, sub-base of 30 cm, and sub-grade of 180 cm was prepared for the experiment of this study. The most important factor of rutting, i.e. temperature, was kept constant at 50℃, and the test section was divided into two sections with different air void of 7% and 10% for APT. Additionally, MDD (Multi-Depth Deflectometer) was installed in these two sections to collect the resilient strain and plastic strain data for the development of a rutting model.

2. RUTTING MODEL

Rutting is a typical damage to asphalt pavement, making it an important factor of determining the performance life of pavement. Rutting was considered to be closely related to vertical strain at upper sub-grade layer in the past, and the design procedure for layer thickness was carried out in the direction of reducing shear stress at sub-grade. However, it is now conceived that the surface rutting can be calculated by summing up rutting of each pavement layer as shown in Equation 1 below (NCHRP, 2002).

$$RD = \sum_{i=0}^{nsublayers} \epsilon_p^i h^i \tag{1}$$

Where,
RD = Rut Depth of Asphalt Pavement,
nsublayer = Number of sub-layer,
ϵ_p^i = Total plastic strain in sub-layer i
h^i = Thickness of sub-layer i

AASHTO 2002 design guide recommends breaking down the prediction equation for permanent deformations separately for asphalt mixture, aggregate sub-base, and sub-grade layer. The following Equation 2 is a prediction equation for rutting at asphalt layer among the prediction equations recommended by AASHTO, and the following Equation 3 is computed by applying calibration parameters of β_{r1}, β_{r2}, β_{r3}, of which values are determined to be 0.509, 0.9, and 1.2, respectively, from experimental values and field measured values.

$$\frac{\epsilon_p}{\epsilon r} = k_1 \times 10^{-3.4488}\, T^{1.5060}\, N^{0.479244} \tag{2}$$

$$k_1 = (C_1 + C_2 \times depth) \times 0.328196^{depth}$$
$$C_1 = -0.1039 \times h_{ac}^2 + 2.4868 \times h_{ac}^2 - 17.342$$
$$C_2 = 0.00172 \times h_{ac}^2 - 1.7331 \times h_{ac}^2 + 27.428$$

Where,
ε_p = Accumulated plastic strain at *N* Repetitions of load
ε_r = Resilient strain of the asphalt material as a function of mix properties, temperature and time rate of loading
N = Number of load repetitions
T = Temperature (˚F)
k_1 = function of total asphalt layers thickness and depth to computational point, to correct for the confining pressure at different depths.

$$\frac{\epsilon_p}{\epsilon r} = \beta_{r1} k_1 \times 10^{-3.4488}\ T^{1.5060\beta_{r2}}\ N^{0.479244\beta_{r3}} \quad (3)$$

Where,
β_{r1}, β_{r2}, β_{r3}= Calibration Parameter

Equation 4 is a permanent deformation prediction equation for the HMA(19 mm dense grade aggregate, AP-5), which is the most similar to the materials used for APT among rutting models of Korean- pavement design method based on laboratory test (Ministry of Land, Transport and Maritime Affairs, 2007). This model includes air void, which is not considered in AASHTO, and predicts the ratio of plastic strain to resilient strain as a function of the temperature of asphalt layer, number of loading repetition, and air void.

$$\frac{\epsilon_p}{\epsilon r} = 10^{0.044}\ T^{0.185}\ N^{-0.708}\ AV^{0.688} \quad (4)$$

Where:
N = Number of load repetitions
T = Temperature (℃)
AV = Air Void (%)

The following Equation 5 is obtained by applying the aforementioned values of calibration factors to Equation 4 above.

$$\frac{\epsilon_p}{\epsilon r} = \beta_{r1} \times 10^{0.044}\ T^{0.185\beta_{r2}}\ N^{-0.708\beta_{r3}}\ AV^{0.688\beta_{r4}} \quad (5)$$

This study aims at collecting the data for the calibration of the parameter of the above rutting model through APT and analyzing the characteristics of the collected data.

3. ACCELERATED PAVEMENT TESTING (APT)

HAPT (Hanyang Accelerated Pavement Tester) as depicted in Figure 1 was deployed for the experiment. The asphalt temperature and air void ratio among three variables of Equation 5 were set to be 50℃ and 7.31% or 10.57% for experimental control, and APT was conducted by the number of loading repetition.

Figure1: HAPT (Hanyang Accelerated Pavement Tester)

The specification of the test section was 12.5m ×3.m ×2.4m (length ×width × depth), and the cross-sectional dimension of the test section was 30cm (asphalt layer), 30cm (sub-base), and 180cm (sub-grade) as illustrated in Figure 2 below. Surface rutting was measured with laser profile meter, and LVDT sensors of MDD were installed at depths of 12cm and 30cm to measure permanent deformation and resilient deflection by air void of the asphalt layer for the computation of rutting of each layer .(Ministry of Land, Transport and Maritime Affairs, 2008).

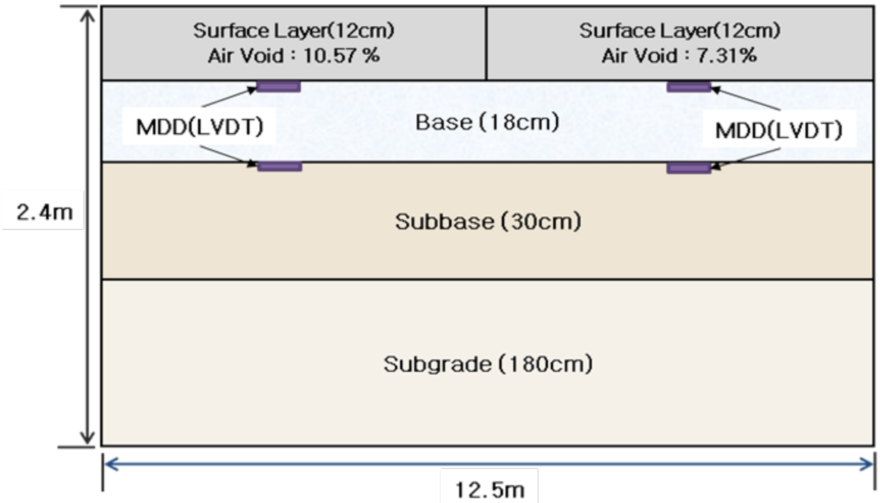

Figure2: Cross-section of the pavement test specimen and location of MDD installation

HMA with AP-5 binder for the surface layer (19mm dense grade, 12cm thickness) and base (25mm dense grade, 18cm thickness), respectively. Additionally, temperature at depths of 2.5, 5, 10, 15, 20, 25cm from the surface was measured to examine the effect of temperature change in each layer on vertical deflection and the temperature change by the depth of the asphalt layer. Given this experimental condition, repetitive loading of 9.0ton (single axle, double wheels) was applied while wandering of Standard Deviation ±0.35m was administered to simulate the distribution of vehicular load on real pavement in the field.

4. APT RESULT

APT was completed when rutting of more than 1/2inch (14.40mm) was observed for the test section with 7.31% air void at surface layer. At this time, rutting of the test section with 10.57% air void was measured at 17.07mm. The APT provided rutting at surface layer with different air void ratios of 7.31% and 10.57% as well as permanent deformation and elastic deflection data at the depths of 12cm and 30cm. The rutting at surface layer of the test section with 10.57% air void was 2.6mm greater than that of the test section with 7.31% air void. On the other hand, the permanent deformation data at depths of 12cm and 30cm as measured with MDD were similar. It indicates that the difference in rutting at the surface layer due to different air void.

4.1 Rutting by Air Void

After controlling for the temperature of the pavement at the depth of 5cm being kept constant at 50℃, repetitive loading was applied to examine the difference in rutting at the surface layer due to different air void of 7.31% and 10.57%. The result is depicted in the graph of Figure 3 below. It shows the difference in rutting due to different air void was constant. The permanent deformation measured with MDD at depths of 12cm and 30cm also exhibited similar pattern and magnitude. Figure 4 shows that when rutting at the surface layer reached 14.40mm and 17.07mm for test sections with different air void, the permanent deformation at 12cm depth was almost same as measured to be 5.3mm and 5.2mm for both test sections. The permanent deformation at 30cm depth was almost same also as measured to be 2.0mm and 1.9mm for both test sections, as shown in Figure 5. It indicates that the difference in rutting at the surface layer due to different air void occurred at surface layer since the surface layer to control for the different air voids.

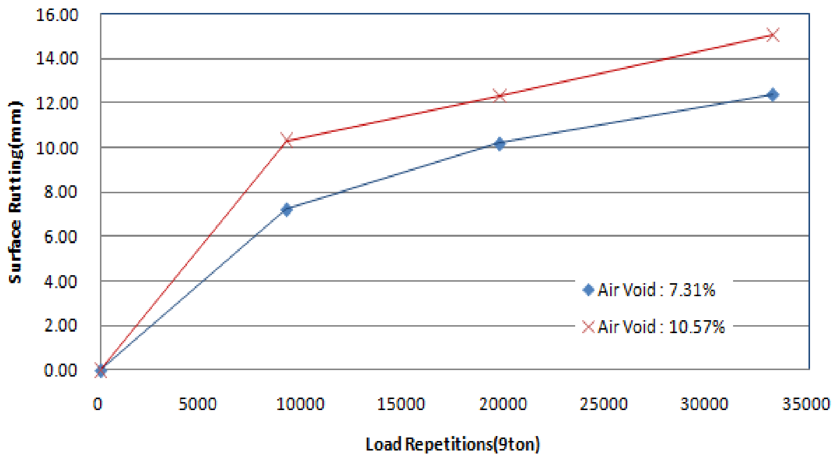

Figure3: Rutting at surface layer

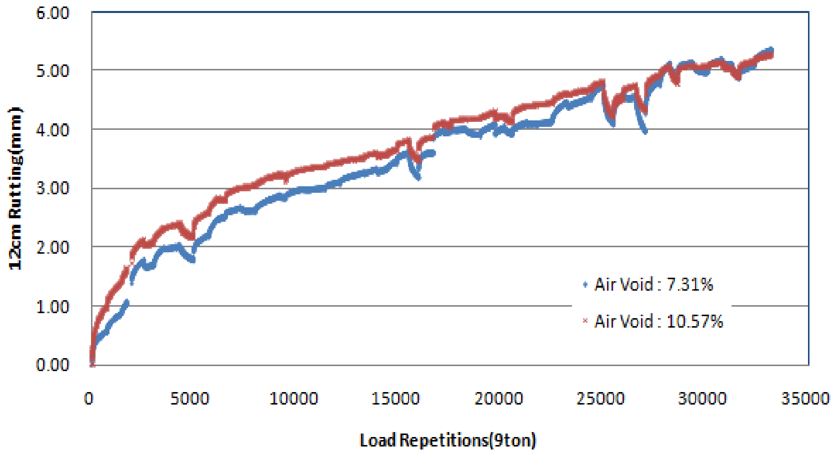

Figure4: Rutting at 12cm depth

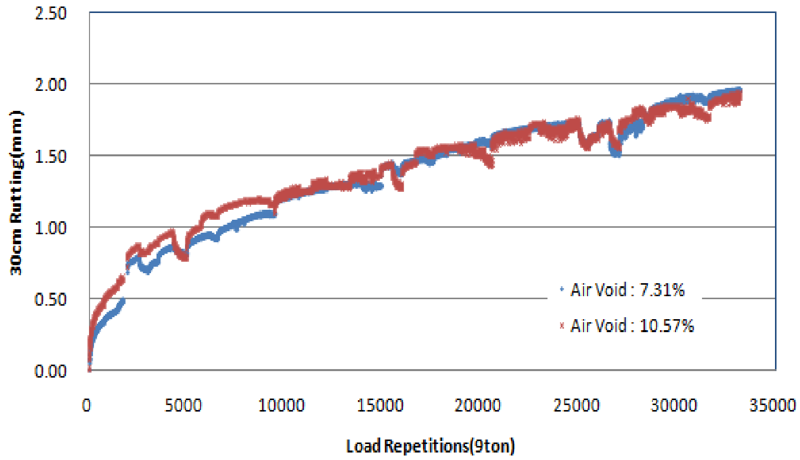

Figure5: Rutting at 30cm depth

4.2 Permanent deformation at Sub-layer

Figures 6 and 7 illustrate permanent deformation of each layer for the two test sections with different air void. It can be seen that the most rutting took place at the surface layer and that the test section with higher air void exhibits about 2.8mm greater permanent deformation at the surface layer. It is reasoned that this difference stems from the fact that the volume of the test section, i.e. air void, due to the loadings.

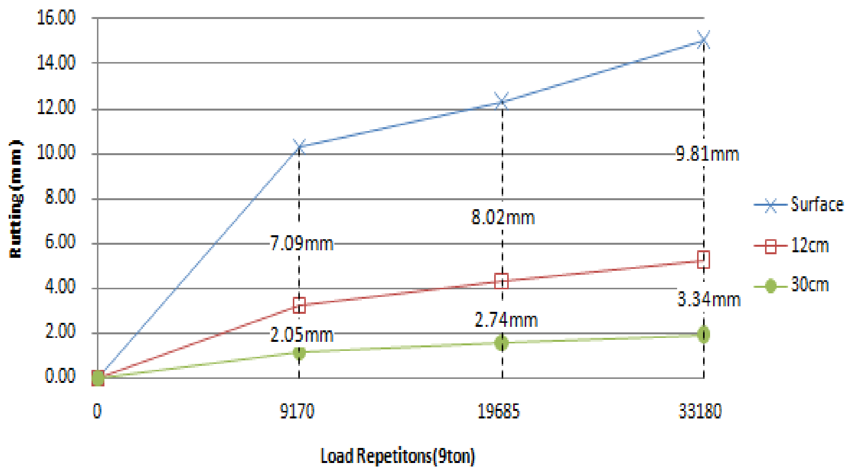

Figure6: Rutting of each layer of the pavement with 10.57% air void

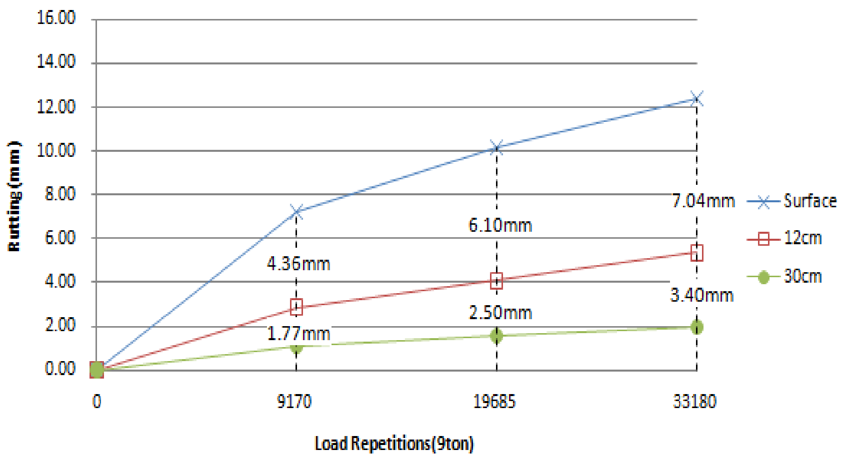

Figure7: Rutting of each layer of the pavement with 7.31% air void

Table 1 compares rutting at surface layer with other layers of different depth and shows rutting at asphalt surface layer (surface ~12cm depth) and base layer (12cm~30cm depth). Although both test section with air void of 10.57% and 7.31% exhibit similar pattern of increasing rutting, the rutting difference is noticeable owing to the difference in air void. On the contrary, permanent deformation at base and sub-base did not differ as shown in Figure 6 and 7.

Rutting at surface layer amounted to about 65% and about 57% of total rutting for the test sections with air void of 10.57% and 7.38%, respectively. Both test sections exhibited about 84% of total rutting at the asphalt layer including the base layer. Rutting at both sub-base and sub-grade amounted to 12 ~16% of total rutting. As it has been shown, the values of Plastic Strain (ϵ_p) due to loading can be obtained from the rutting measurements at each layer, and this can be used as the data necessary for the calibration of the parameter of rutting model.

Table1: Rutting of each layer

classification	10.75% air void section rutting of each layer (mm)				7.31% air void section rutting of each layer (mm)			
Load Repetitions (9ton)	Total	Surface	Base	Subbase +Subgrade	Total	Surface	Base	Subbase +Subgrade
		Asphalt Layer				Asphalt Layer		
9,170	10.32	7.09 (68.8%)	2.05 (19.9%)	1.18 (11.43%)	7.24	4.36 (60.3%)	1.78 (24.5%)	1.10 (15.2%)
		9.15(88.9%)				6.14(84.8%)		
19,685	12.33	8.02 (65.0%)	2.74 (22.3%)	1.57 (12.7%)	10.19	6.10 (59.9%)	2.50 (24.5%)	1.59 (15.6%)
		10.76(87.3%)				8.61(84.4%)		
33,180	15.07	9.81 (65.1%)	3.34 (22.2%)	1.92 (12.7%)	12.40	7.04 (56.8%)	3.40 (27.4%)	1.60 (15.8%)
		15.15(87.3%)				12.44(84.2%)		

4.3 Resilient deflection by Sub-layer

The resilient deflection data due to loading were obtained by MDD installed at 12cm and 30cm depth from the surface, and the result is shown in Figure 8 and Figure 9. The resilient deflection differed greatly by the location of loading, i.e. wandering, and it was greater for the test section with higher air void.

The values of resilient strain (ϵ_r) taking place at the depth between 12cm and 30cm could be obtained from the measured data of resilient deflection at 12cm and 30cm, and its mean and standard deviation were 5.4×10^{-4} and 3.4×10^{-4}. This distribution is construed to be due to the difference in resilient deflection by the loading location caused by wandering.

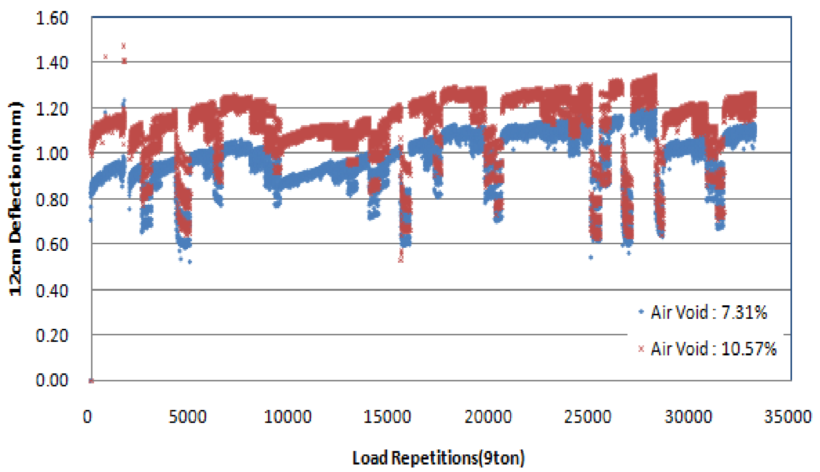

Figure8: Resilient deflection at 12cm depth

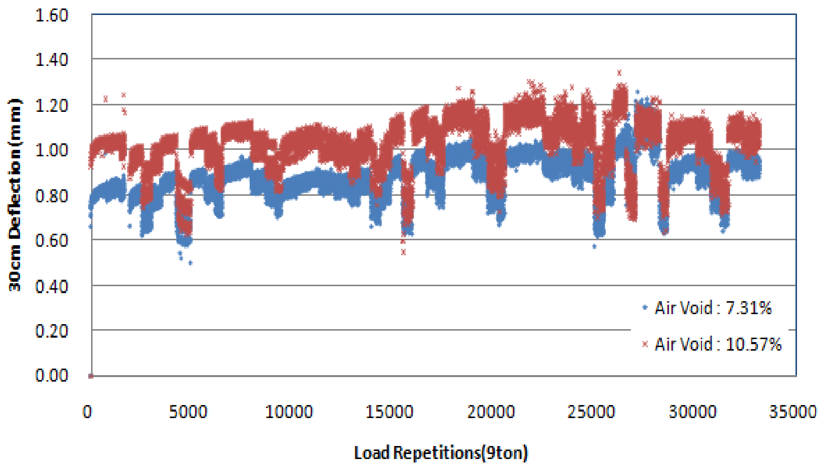

Figure9: Resilient deflection at 30cm depth

5. CONCLUSIONS

Experiments were conducted to obtain the data for the development of a rutting model of asphalt pavement with HMA(19mm dense grade) while controlling for the temperature at the 5cm depth being kept constant at 50℃. The following conclusions are derived from the results of this research.

(1) This study collected permanent deformation data and resilient deflection data to obtain the values of Plastic Strain (ϵ_p) and Resilient Strain (ϵ_r), respectively, which are necessary for the rutting model of asphalt pavement. The experiment was conducted on HMA(AP-5 binder, 19mm dense grade) and divided into two sections of two different air void, while controlling for the temperature at being kept constant at 50℃.

(2) The APT (Accelerated Pavement Testing) experiment ended when rutting of more than 1/2inch (14.40mm) was observed for the test section with 7.31% air void at surface layer. At this time, rutting of the test section with 10.57% air void was measured at 17.07mm.

(3) The permanent deformation data at depths of 12cm and 30cm as measured with MDD were similar. It indicates that the difference in rutting at the surface layer due to different air void.

(4) Rutting at surface layer amounted to about 65% and about 57% of total rutting for the test sections with air void of 10.57% and 7.38%, respectively. Both test sections exhibited about 84% of total rutting at the asphalt layer including the base layer. Rutting at both sub-base and sub-grade amounted to 12 ~16% of total rutting.

(5) Most rutting took place at the asphalt layer. The result of varying the air void of the asphalt pavement by 3% (7.38% vs. 10.57%) and analyzing rutting of each layer showed that the difference in rutting between the two test sections with different air voids accounted for the total rutting difference, and the difference was about 2.6mm (difference in rutting taking place at surface layer and interface: 2.8mm).

(6) The values of Resilient Strain (ϵ_r) taking place at the depth between 12cm and 30cm could be obtained from the measured data of resilient deflection at 12cm and, and its mean and standard deviation were 5.4×10^{-4} and 3.4×10^{-4}. This distribution is construed to be due to the difference in resilient deflection by the loading location caused by wandering.

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