

Environment Friendly Asphalt in Industrial Roads (Green Roads)

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The main objective of Yanbu Industrial City Economic review is to gain better and current understanding of the city wide economic performances. The specific objectives are:

- To monitor / keep track of City's economic trends on a quarterly basis.
- To understand the changes in the economic structure of the city over the period of time.
- To generate economic awareness.

Yanbu Industrial City is located 350 Kilometers north west of Jeddah. It possesses tourism features due to its location on a coastal line the red sea and hijaz hills. The red sea with its crystal water and attractive coral reefs welcomes the people who visit and frequent it for marine picnics, diving and several types of water sports. In this young city – just over 40 years became a center for modern industries. It plays a major role in Kingdom's gross national income.



Yanbu port includes the facilities that enable it export more than three (3) million barrels / day while its location near the Suez channel makes it an excellent access to European markets and the developing markets in Affric and Middle East. Yanbu, moreover is located in the middle of the distance between America and the countries of the pacific ocean.

The Royal Commission vision is "The best choice for investors in petrochemical and energy-intensive industries and the leading contributor to the Kingdom's growth.

The Royal Commission Mission is "Plan, promote, develop & manage petrochemical and energy intensive industries through successful focus and partnerships with investors, employees, communities and other stakeholder

The Royal Commission’s strategic objectives are:

- Growth: Expand industrial base through growth in number of cities and industrial output.
- Tenant Portfolio: Optimize tenant portfolio by attracting investments of added value.
- Cities of Excellence: Gain recognition as one of the top industrial cities globally.
- Distinctive Staff : The best in attracting distinctive human resources in the Kingdom
- Financial: Gradually develop financial sustainability and increased efficiency.

➤ EXISTING COMMUNITY AREA = 7,000 HA
 ➤ EXISTING INDUSTRIAL AREA = 11,500 HA
EXPANSION AREA = 42,100 HA
TOTAL AREA OF RC YANBU = 60,600 HA (606 SQ. KM)

Royal Commission at Yanbu Industrial City, Saudi Arabia was keen to raise the efficiency of its main & secondary roads network in Industrial Yanbu due to its strategic location in the kingdom’s map and its association with neighboring countries. Our goal is to provide a safe roads network with high quality specifications without defects, that includes the study for an advanced asphalt mix design system where Industrial Yanbu will expand significantly in industrial, urban and investment field.

Type of road	Kilo meter	meter	Square meter
Highway (TAMA & Bypass Road)	124	124,300	3,395,600
Primary Streets (Main Roads)	102	101,400	2,183,000
Secondary Streets	101	100,950	1,736,350
Tertiary Streets	195	195,350	1,707,950
Parking Area	-	-	296,000
Total	522	522,000	9,318,900

The roads in Yanbu Industrial City were frequently damaged due to the extensive use of overloaded trucks without using control or balance weight, mainly on highway and roads in heavy & light industrial park areas, resulting in asphalt rutting, cracks, bleeding, etc. (See Figure # 1).



Figure # 1; Deformation of asphalt pavements

In 2014, the Royal Commission for Yanbu bought an Equipment for the Evaluation of the roads to establish maintenance priorities. Condition data such as roughness, rutting, cracks and surface distress, and deflection are used to establish the projects most in need of maintenance and rehabilitation. Once identified, the projects in the poorest condition are more closely evaluated to determine repair strategies (See Figure # 2).



Figure # 2; Road survey / evaluation equipment

The Royal Commission conducts studies to overcome the asphalt pavement deformation problems for intersections and industrial roads and end up with three (3) major solutions:

- 1) Use of marshal Mix Design
- 2) Use of Reinforced Concrete pavement instead of asphalt
- 3) Use of Super pave Mix Design

Since 2004, the Royal Commission used the Marshall mix design of asphalt for rehabilitation industrial roads and intersections of highway road. The Marshall Mix Design method were originally developed by Bruce Marshall of the Mississippi Highway Department around 1939 and then refined by the US Army. This method is very popular because of its relative simplicity, economical equipment and proven record. The Marshall method seeks to select the asphalt content at a desired density that satisfies minimum stability and range of flow values. The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C.

Construction of asphalt pavement using Marshall mix design method is relatively economical but it has some major drawbacks (See Figure # 3 & 4).

- 1) Less pavement strength.
- 2) Low resistance of rutting and cracking.
- 3) Short service life.
- 4) Requires regular maintenance, so uneconomical.

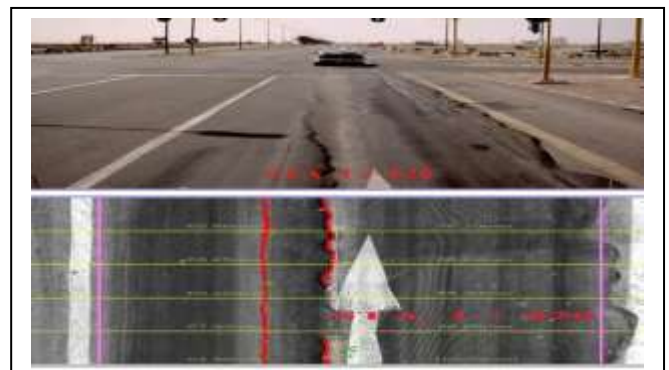


Figure # 3; Road survey by evaluation equipment

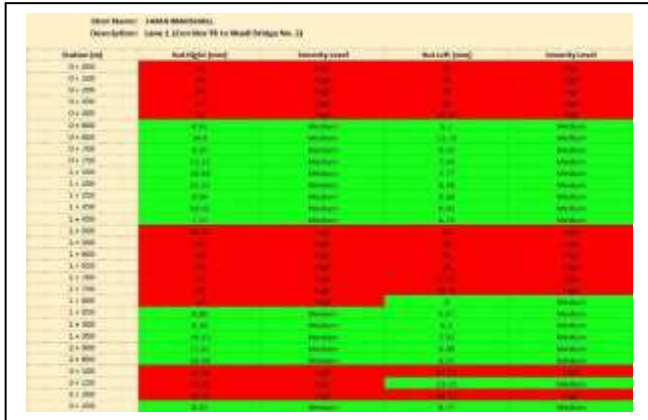


Figure # 4; Road survey results from evaluation equipment

Due to the increment in traffic volume, especially heavy trucks and trailers, The Royal commission decided to go through the second method that was Rehabilitation of Roads using Reinforced Concrete pavement instead of asphalt. The application was limited to intersections with rutting problem (See Figure # 5).

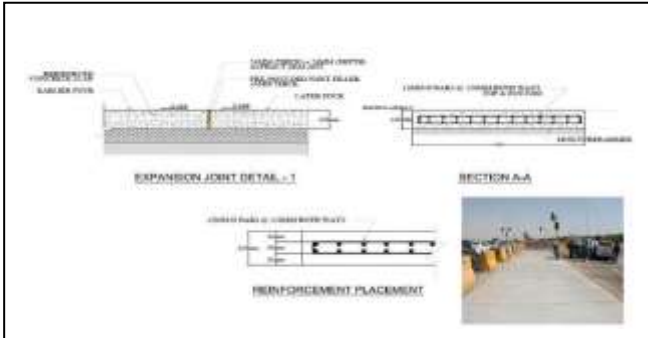


Figure # 5; Section details of reinforced concrete pavement

The advantages of this method are:

- 1) Improved skid resistance compared with traditional type of asphalt pavement.
- 2) Better visibility at night time and less glare.
- 3) Long Service life.

The disadvantages are:

- 1) High construction cost.
- 2) Less resistance of transverse cracking compare with Marshall mix design.
- 3) Increase pavement noise due to expansion joints and type of surfacing pattern (transverse thinking).

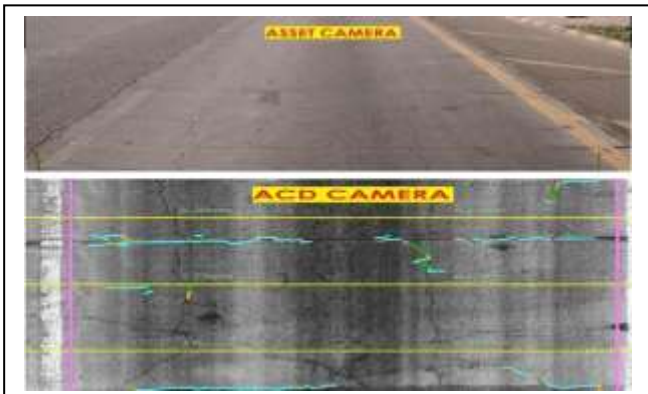


Figure # 6; Road survey by evaluation equipment

Chainage (m)	Cracks Percentage (%)	Extent Level	Av. Crack Width (mm)	Severity Level	Crack Length (m)
800	6.87	Occasional	0.25	Medium	6.00
850	11.39	Occasional	0.40	Medium	6.38
900	6.87	Occasional	0.20	Medium	6.82
950	6.95	Occasional	0.20	Medium	7.00
1000	6.29	Occasional	0.20	Medium	7.28
1050	0.87	Occasional	0.20	Medium	0.50
1100	7.29	Occasional	0.20	Medium	7.88
1150	4.00	Occasional	0.20	Medium	3.28
1200	2.39	Occasional	0.20	Medium	0.88
1250	6.29	Occasional	0.20	Medium	11.88
1300	6.90	Occasional	0.20	Medium	5.85
1350	2.87	Occasional	0.20	Medium	0.22
1400	5.35	Occasional	0.20	Medium	3.06
1450	2.87	Occasional	0.20	Medium	0.28
1500	1.85	Occasional	0.20	Medium	0.57
1550	3.35	Occasional	0.20	Medium	2.37
1600	5.35	Occasional	0.20	Medium	4.89
1650	5.35	Occasional	0.20	Medium	4.21
1700	2.87	Occasional	0.20	Medium	0.28
1750	1.26	Occasional	0.20	Medium	1.15
1800	2.90	Occasional	0.20	Medium	0.88
1850	5.35	Occasional	0.20	Medium	0.87
1900	14.37	Occasional	0.20	Medium	114.84
1950	6.90	Occasional	0.20	Medium	7.20
2000	6.29	Occasional	0.20	Medium	12.88
2050	1.85	Occasional	0.20	Medium	0.88
2100	4.87	Occasional	0.20	Medium	2.88
2150	14.87	Occasional	0.20	Medium	25.24

Figure # 7 ; Road survey results from evaluation equipment



Figure # 8 ; Maintenance of cracks by crack sealing

In 2016, many studies and site visits were conducted including the road survey analysis by Royal Commission's Road Evaluation Equipment which can provide the detailed reports like type of deformation of asphalt layers, degree of damage in asphalt layer, cracks, rutting, etc. Moreover, the Royal Commission Roads Department was coordinated and discussed with several consultants around the globe to find out the right solution to avoid deformation in asphalt pavement at the industrial roads. Furthermore, Roads Department conducted site visits in all batch plants in Yanbu in order to check the quality of the materials used for mix design. Based on the thorough evaluation results, The Royal Commission decided to execute the third method as trial, since the previous methods are not suitable for the industrial city being un-efficient and un-economical. We applied the wearing course by super pave mix design on the existing asphalt base course having Marshall Mix design. This procedure established the precedent in the world. This method is called environment friendly asphalt layer in Industrial Roads (Green Roads).

The Royal Commission decided to execute the third method (superpave mix design) at the critical locations, including:

- Applying super pave mix design in light industrial area
- Applying super pave mix design at intersections along King Abdulaziz highway (TAMA)

The Royal Commission Roads Department was executed the following steps:

Step # 1 : Count the number of vehicles and Trucks using yanbu industrial city Roads (see Figure # 9).

RTMS	TOTAL RTMS GENERATED COUNTS WITH VEHICLE CLASSIFICATION				GRAND TOTAL	ESTIMATE YEARLY TOTAL
	SMALL-6.2M PASSENGER CARS	MEDIUM-3-10.1M COASTER, VAN, TRUCK	LARGE-10.1-12M BUS, TRUCK SINGLE UNIT	TRUCK >12M TRUCK, TRAILER TRUCK		
RTMS TOTAL FOR THE YEAR 2014	2,780,535	387,824	78,740	910,588	3,737,888	44,854,658
RTMS TOTAL FOR THE YEAR 2015	2,838,457	378,528	74,168	838,872	3,888,023	45,926,276
RTMS TOTAL FOR THE YEAR 2016	3,023,386	371,875	88,577	484,121	4,068,372	49,180,484
RTMS TOTAL FOR THE YEAR 2017	3,180,485	374,901	98,503	480,286	4,324,129	51,889,548

Figure # 9; RTMS Data

Step # 2 : Compare with standards (see Figure # 10).

Class Designation		ESALs Range	Applications
VL	Very Light	Less than 300,000	Agricultural roads with light traffic , local and city streets without trucks
L	Light	300,000 to 3 million	Agriculture, Feeder and collector roads
M	Medium	3 million to 10 million	Main roads and city streets
H	Heavy	10 million to 30 million	Highways and Expressway
VH	Very Heavy	More than 30 million	Heavily trafficked highways, industrial areas ...

Figure # 10; ESAL and traffic Designation

Step # 3 : Determine Super pave Mix Design requirements (see Figure # 11).

The Super pave mix design method was designed to replace the Hveem and Marshall methods. Final product of the 1987-1993 FHWA Strategic Highway Research Program to investigate better pavement materials & design methods. The Super pave (Superior Performing Asphalt Pavements) mix design method ties asphalt binder and aggregate selection into the mix design process, and consider traffic and climate as well. The compaction devices from the Hveem and Marshall procedures have been replaced by a gyratory compactor and the compaction effort in mix design is tied to expected traffic.

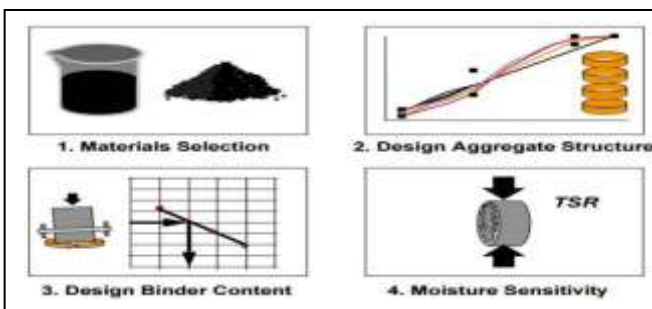


Figure # 11; Steps of Super pave mix design

The Super pave mix design Evaluation Criteria includes the following:

- 1) Specimen heights
- 2) Mixture volumetric
 - a. Air voids
 - b. Voids in mineral aggregate (VMA)
 - c. Voids filled with asphalt (VFA)
 - d. Mixture density characteristics
- 3) Dust proportion
- 4) Moisture sensitivity

The Crushed Fragments in Gravels used as aggregate shall have the following characteristics:

- 1) Quarried materials always 100% crushed minimum two sides of aggregate(See Figure # 12).
- 2) Minimum values depended upon traffic level and layer (lift).
- 3) Defined as percentage mass with one or more fractured faces.

Crushed face aggregates helps to reduce shear plane slides and mass deformation of the pavement structure.

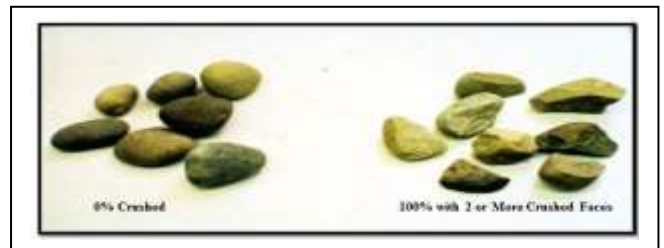


Figure # 12; Crushed fragments in gravel

Super pave Asphalt Binder Specification (Performance Grade Specification) depends on the following (see Figures # 13 & 14):

- 1) Fundamental properties related to pavement performance.
- 2) Environmental factors.
- 3) In-service & construction temperatures.
- 4) Short and long term aging.

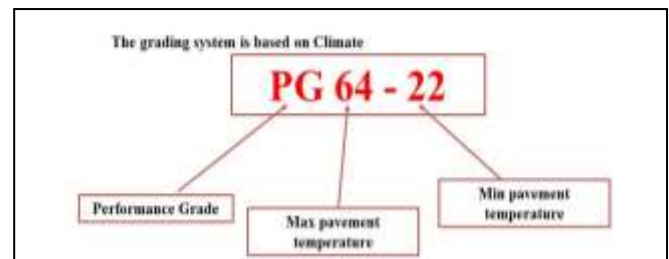


Figure # 13; Super pave asphalt binder grading system

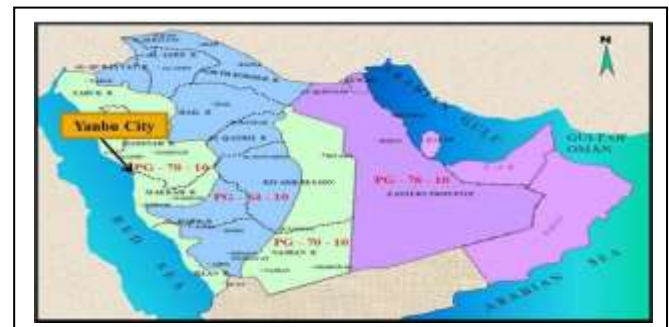


Figure # 14; The grading system is based on Climate in KSA

Asphalt cement is a viscoelastic material and its behavior depends on the following:

- 1) Temperature
- 2) Time of loading
- 3) Aging (properties change with time)

Step # 4 : Site visit to Asphalt patch plant:

Visiting of asphalt patch plant is important step to check How we can apply and requirement of super pave mix design (see figure # 15).



Figure # 15; Visit to asphalt batch plant

Step # 5 : preparation of super pave mix design in patch plant (see figure # 16).



Figure # 16; preparation of super pave mix

Step # 6 (a) : Applying super pave mix design in light industrial area (see figure # 18)

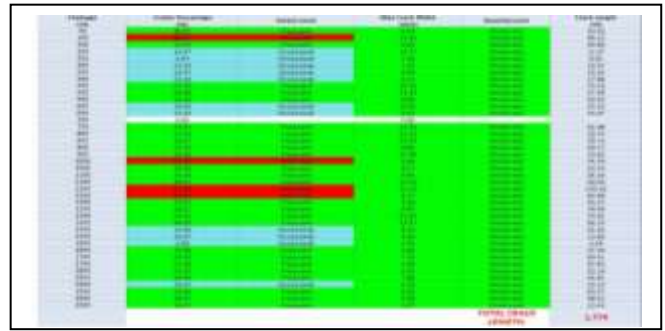
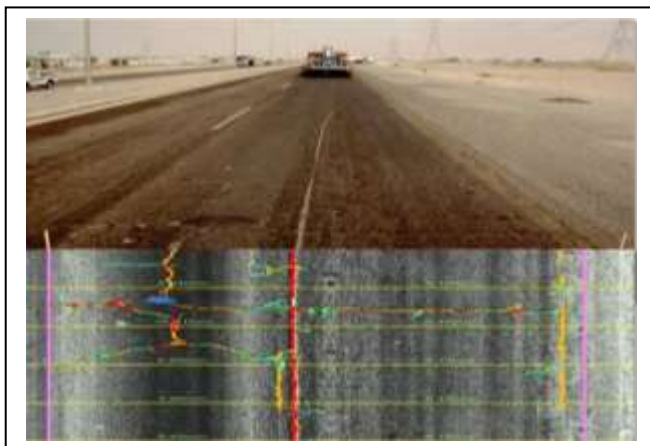


Figure # 17: Condition of asphalt layers at light industrial park before the application of super pave



Figure # 18; rehabilitation of roads in light industrial parks

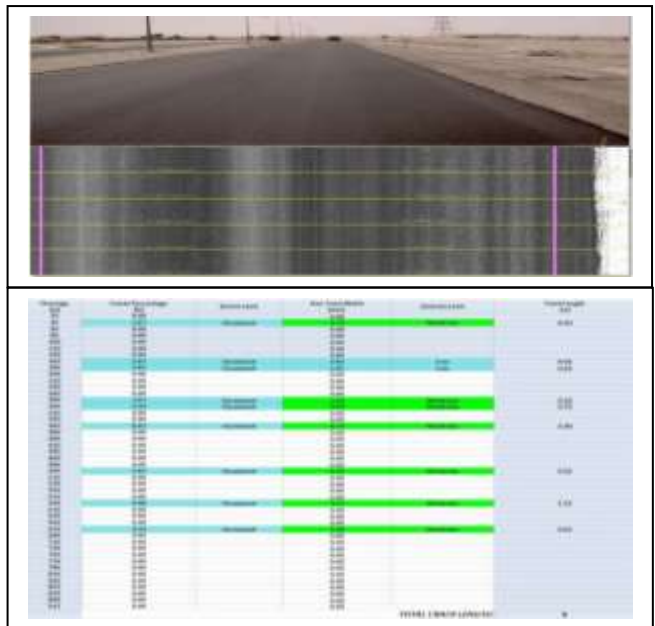
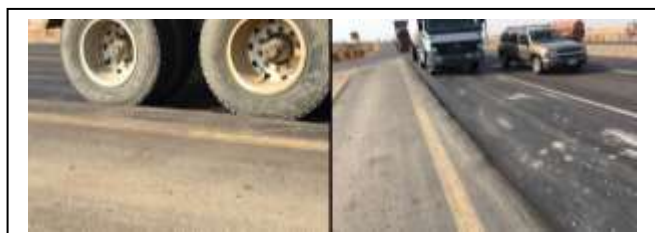


Figure # 19: Condition of asphalt layers at light industrial park after the application of superpave

Step # 6 (b) : Applying super pave mix design at intersections along King Abdulaziz highway (TAMA)



Station (m)	Red Right (mm)	Severity Level	Red Left (mm)	Severity Level
0+000	10	High	10	High
0+100	10	High	10	High
0+200	10	High	10	High
0+300	10	High	10	High
0+400	10	High	10	High
0+500	0.91	Medium	6.2	Medium
0+600	29.8	Medium	31.71	Medium
0+700	6.26	Medium	4.86	Medium
0+750	11.11	Medium	1.86	Medium
1+000	81.86	Medium	7.77	Medium
1+200	11.57	Medium	6.58	Medium
1+250	6.94	Medium	6.91	Medium
1+300	10.81	Medium	6.51	Medium
1+400	7.75	Medium	6.75	Medium
1+500	10.86	High	10	High
1+550	10	High	10	High
1+600	10	High	10	High
1+650	10	High	10	High
1+700	10	High	17.10	High
1+750	10	High	10.20	High
1+800	10	High	9	Medium
1+850	6.81	Medium	1.87	Medium
1+900	6.66	Medium	6.2	Medium
1+950	10.11	Medium	7.20	Medium
2+000	11.81	Medium	4.86	Medium
2+050	11.70	Medium	3.41	Medium
3+000	10.86	High	10	High
3+100	10.11	High	11.21	Medium
3+200	10.86	High	10	High
3+250	6.26	Medium	6.75	Medium
3+300	6.26	Medium	6.75	Medium

Figure # 20: Condition of asphalt layers at intersections along highway (TAMA) before the application of superpave

Station (m)	Red Right (mm)	Severity Level	Red Left (mm)	Severity Level
0+000	0.91	Low	6.91	Low
0+100	0.91	Low	6.91	Low
0+200	0.91	Low	6.91	Low
0+300	0.91	Low	6.91	Low
0+400	0.91	Low	6.91	Low
0+500	0.91	Low	6.91	Low
0+600	0.91	Low	6.91	Low
0+700	0.91	Low	6.91	Low
0+800	0.91	Low	6.91	Low
0+900	0.91	Low	6.91	Low
1+000	0.91	Low	6.91	Low
1+100	0.91	Low	6.91	Low
1+200	0.91	Low	6.91	Low
1+300	0.91	Low	6.91	Low
1+400	0.91	Low	6.91	Low
1+500	0.91	Low	6.91	Low
1+600	0.91	Low	6.91	Low
1+700	0.91	Low	6.91	Low
1+800	0.91	Low	6.91	Low
1+900	0.91	Low	6.91	Low
2+000	0.91	Low	6.91	Low
2+100	0.91	Low	6.91	Low
2+200	0.91	Low	6.91	Low
2+300	0.91	Low	6.91	Low
2+400	0.91	Low	6.91	Low
2+500	0.91	Low	6.91	Low
2+600	0.91	Low	6.91	Low
2+700	0.91	Low	6.91	Low
2+800	0.91	Low	6.91	Low
2+900	0.91	Low	6.91	Low
3+000	0.91	Low	6.91	Low
3+100	0.91	Low	6.91	Low
3+200	0.91	Low	6.91	Low
3+300	0.91	Low	6.91	Low
3+400	0.91	Low	6.91	Low
3+500	0.91	Low	6.91	Low
3+600	0.91	Low	6.91	Low
3+700	0.91	Low	6.91	Low
3+800	0.91	Low	6.91	Low
3+900	0.91	Low	6.91	Low

Figure # 21: Condition of asphalt layers at intersections along highway (TAMA) after the application of superpave

The advantages of super pave asphalt mix design are:

- 1) Reduced the amount and severity of pavement distresses.
- 2) Improved stability to prevent rutting.
- 3) Improved flexibility to prevent cracking
- 4) Improved durability to prevent potholes / weathering.
- 5) Long service life.
- 6) Low maintenance cost.
- 7) Less pavement noise.
- 8) Provide excellent riding quality.

The Royal Commission experiment for using the Super pave asphalt mix design in operation & maintenance and construction projects offers:

- 1) Sufficient asphalt to ensure a durable pavement.
- 2) Sufficient stability under traffic loads.
- 3) Sufficient air voids.
- 4) Upper limit to prevent excessive environmental damage.
- 5) Lower limit to allow room for initial densification due to traffic.
- 6) Sufficient workability and Sufficient skid resistance.

By this way the Royal Commission can provide to the motorist an Environment friendly asphalt industrial roads is calling (green roads).

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References:

- *American Association of State Highway and Transportation Officials (AASHTO):*
- *American Society for Testing and Materials (ASTM):*
- *Saudi Arabian Standard - Ministry of Transport (MOT) Standard Specifications for Road and Bridge Construction:*