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EFFECT OF EXTERNAL FACTORS ON PERMENENT DEFORMATION BEHAVIOR OF LOCAL ASPHALT PAVEMENTS

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ABSTRACT

Permanent deformation (rutting) is considered one of the most important factors that reduces pavement life in roads network and highways in Iraq. In this paper, a laboratory investigation has been conducted to evaluate the effect of external factors on rutting of asphaltic mixture. The study was carried out using local materials for the surface layer. Three levels of temperature were examined namely, 40, 50, and 60 °C, in addition to three stresses intensities are 700N, 900N, and 1100N were investigated for wheel track test, and 10, 20, and 30 psi of repeated load were also tested. The results have cleared that the temperature and stress have a significant effect on the permanent deformation. Where mixtures resistance to rutting increases about 57.65% when temperature degree increases from 40 °C to 50 °C. Also, increasing load intensity from 700 to 900 N resulted in higher rutting values (about 40.75% increase has observed in term of WTT). Additionally, increasing temperature from 40 °C to 50 °C resulted in permanent strain and resilient strain increase by 84.49 % and 11.27 %, respectively. Also, increasing load intensity from 10 to 20 psi resulted in higher permanent strain and resilient strain values about 5.44 % and 27.94 %, respectively, for wearing layer. In term of uniaxial repeated load test, it has concluded that temperatures and stresses employed for design are relative high to reproduce the most unfavorable pavement conditions.

KEY WORDS: Rutting deformation, Wearing layer, Wheel track, Stress effect, Temperature, Pneumatic Repeated Loads.

1. INTRODUCTION

The permanent deformation of asphalt pavements has an important impact on the performance of the pavements during their life time. It is reduced not only the useful service life of pavements, but it may affect basic vehicle handling, which can be hazardous to highway users. Rutting (which considers one type of permanent deformation) develops gradually as the number of load applications increases and appears as longitudinal depression in the wheel paths and small upheavals to the sides. It is caused by a combination of densification and shear deformation; the main contributing factors are traffic, especially heavy loads, and high temperatures. These depression or ruts are important because if the surface is impervious, the ruts trap water causing hydroplaning (particularly for passenger cars), which is extremely dangerous. As the ruts become deeper, steering becomes increasingly difficult, leading to greater safety concerns (Oda et al., 2012) and (Sousa et al., 1991). In recent years, road pavement has been subjected to greater damages as a result of increase in number and weight of vehicles passing on roads. One of the most common types of road damaging is rutting which has a noticeable impact on performance of road pavement during its service life. Rutting is defined as the accumulated permanent deformation of road pavement which occurs under applied loading (Matthews and Monismith, 1992) and (Abdulshafi, 1988). Rutting of hot mix asphalt (HMA) pavement at or near intersections is very common both in cold and hot climates. Obviously, the problem is more acute in hot climates compared to cold climates because the stiffness of HMA decreases with increase in the pavement temperature. In most cases, there is no significant rutting in the same asphalt pavement structure away from the intersections under fast moving traffic (Kandhal et al., 1998).

1.1. Traffic Characteristics

Passing vehicles induce loads to the pavement directly beneath the tire. Low vehicle speed implies high loading time, which equals low frequency. The stiffness of the asphalt will decrease under these conditions. This low speed will cause high flow rutting (Epifanio and Gan, 2009). Heavy vehicles have traditionally used conventional dual tires, but the use of singled-out dual tires and super-single tires is increasing steadily. This is due to such benefits as lower vehicle weight and lower rolling resistance (Epifanio and Gan, 2009). The economics of truck moving has led to the rate gross weight of trucks to become higher, so that a majority of trucks is operating close to the legal axle loads areas. In countries where assessment of the legal axle load permitted is relaxed or not found (ideally of developing countries), trucks operate at axle loads, which by far exceed the legal axle load permitted. As axle loads have become higher, the use of higher tire pressures has become more common the industry of vehicles. More tire pressures lessen the attachment area of the tire and the pavement, leads to pressure takes part in the larger defect in flexible pavements, manifested as severe wheel track rutting. Because of the increased tire pressure and axle load, the upper layer of asphalt layer suffers from more stresses, which results in permanent (irrecoverable) deformations (Garba, 2002). Believes that the weight carried by the wheel is uniformly distributed over a circular area, and the radius of loading area is obtained from the weight of the vehicle and the pressure of the tyro (Huang, 2004). The current guide for design of pavement structure (AASHTO, 2010) is based on 18 kips loads and tire contact pressure of 75 to 80 psi.

1.2. Environmental Conditions

The degree of the weather is an important factor that can influence the rutting characteristics of asphalt mixture, and this depends on the asphalt characteristics, which are highly influenced by a considerable degree (Baghaee et al., 2014).

The time required to achieve 10 mm rutting depth in asphalt concrete at 50 °C is 72 % shorter than that required at 40 °C (Yassoub, 2005). when the heat goes up from 20 °C to 40 °C, the permanent deformation becomes higher by a factor 4.8 while an increasing from 40 °C to 60 °C causes higher factor to 5.13 (Albayati, 2006). That repeated load permanent deformation appears for asphaltic surface coarse mixes indicating that increasing of testing temperature from 40 °C to 55 °C the permanent deformation rises by 64 %. Similarly, (Abed, 2010), (Mahboub and Little, 1988) conservatively selected the hottest pavement profile to represent the critical condition (as refers by (Sousa et al., 1991)). Other assumptions about the accumulation of permanent deformation in Texas pavements included the following:

1. Permanent deformation occurs daily over the time interval from 7:30 a.m. to 5:30 p.m.;
2. Permanent deformation occurs only in the period from April to October, inclusive; and
3. Permanent deformation can be ignored at temperatures below 50 °F.

Based on wheel tracking tests to evaluate some of the pavement mixtures conventionally used in Singapore, states the following after 10800 passes of load, at 35 °C and 60 °C temperatures, the corresponding rut depth is 3.89mm and 12.95mm, respectively, i.e., 70 percent of rut depth was developed at 60 °C (Fwa and Tan, 1992).

2. MATERIAL

2.1. Asphalt cement

One type of asphalt binder was employed from AL Daurah refinery with type (40-50) asphalt cement grade binder. The tests conducted on asphalt cement confirm that its characteristics comply with the specifications of (GSRB), section R9 (GSRB, 2003). The physical properties of these binders are presented in Table 1.

Table 1. Physical properties of asphalt binder.

Test	Test conditions	ASTM Designation	Units	Value of test	Specification limits of Asphalt Binder Grade (40-50)
Penetration	100gm, 25 °C, 5 sec., 0.1 mm.	D5 (ASTM, 2015)	1/10 mm	25	(40-50)
Specific Gravity	25 °C	D70 (ASTM, 2009)	----	1.04	(1.01-1.05)
Ductility	25 °C, 5 cm/min	D113 (ASTM, 2007)	cm	131	>100
Flash Point	-	D92 (ASTM, 2005)	°C	256	>232
Softening point	(4±1) °C/min.	D36 (ASTM, 2000)	°C	53	(52-60)

2.2. Aggregate and selected gradations

Course and fine aggregate that is used in this work is crushed quartz from Al-Kut province (Badra). One aggregate gradation was used in this work as shown in Fig. 1. The size of coarse aggregate ranges between 3/4 in (19mm) and NO.4 sieve (4.75). The aggregate gradation for wearing course type IIIA was selected according to the stated Iraqi specification; (GSRB), section R9 (GSRB, 2003).

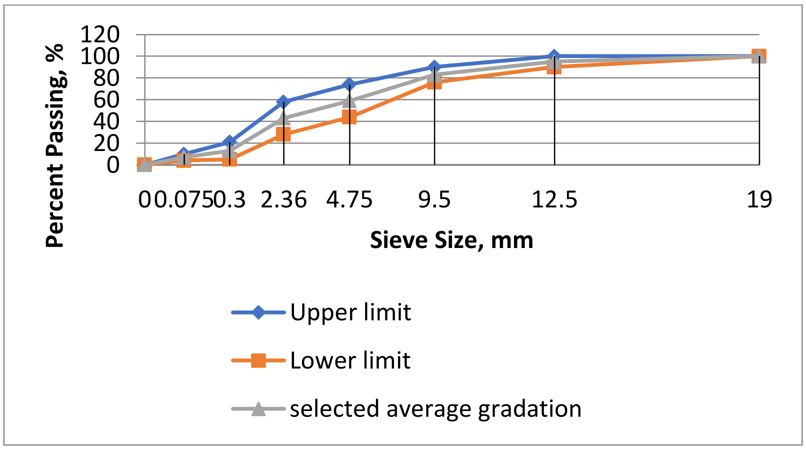


Fig. 1. Asphalt Mixture Gradation with Iraqi Specification Limits for Wearing Course (GSRB, 2003).

2.3. Mineral Filler

Ordinary Portland cement was used to represent the fine materials size in hot mix asphalt (HMA). Table 2 clears the physical properties of filler used in HMA.

Table 2. Physical Properties of Mineral Filler.

Property	(GSRB, 2003) requirement	Test results %
Specific Gravity	-	3.012
Passing sieve No.200	90% Min	96

3. PREPARATION OF MIXES

The preparation included heating aggregate to 150 °C and asphalt binder to 135-140 °C with mixing temperature not less than 120 °C. In a brief way, five sets groups with 3 specimens for each one were prepared to determine the optimum binder content for the mix. Several trials were made starting with 4% of asphalt content with 0.5 incremental step. The compaction effort was 75 blows each face which were applied by using of a standard Marshall Hammer. With the optimum gradation determined, the asphalt content is now varied to determine the optimum asphalt content. Marshall Method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures loaded on the lateral surface by means of the Marshall apparatus according to ASTM (D 1159).

4. WHEEL TRACK TEST

Wheel track test is a famous test which simulates wheel load under pavement surface. Numerous researchers used such test to identify resistance of asphalt mixtures to rutting. The preparation, compaction, conditioning, and testing of asphalt specimens shall be described which is illustrated in Table 3.

5. PNEUMATIC REPEATED LOADS TESTING (PERMANENT DEFORMATION)

Pneumatic repeated load system device was used to test the specimens and measure the vertical displacement occurred in the specimen during the uniaxial compressive repeated loading test. For each asphalt mix, the number of load repetition (N) was plotted against the plastic strain in log-log scale to show the effect of each variable on the determination of the plastic strain (Hilal, 2011).

Table 3. Test conditions for Wheel Track Testing.

Item	range	value
No. of required specimens	1	1
Diameter of rubber wheel	203.2 mm	203.2 mm
Wide rubber wheel	50 mm	50 mm
No. of wheel pass per min.	50 ∓5	50
Speed of wheel	Max. 0.305 m/s	0.305 m/s
Load on the wheel	705∓4.5 N	705.5 N
No. of cycles	1000	1000
Specimen thickness	38 - 100 mm	50-60
Air void content specimens	7∓2 %	Middle value according to Iraqi specifications (GSRB, 2003)
Test temperature ºC	25-70 ºC	40,50 &60 °C
Specimens type	Rectangular or Cylindrical	Rectangular 5x16x30
Compaction	According to air void	

6. RESULTS AND DISCUSSION

6.1. Marshall Test Method

This method covers the measurement of the resistance to plastic flow of cylindrical asphalt specimens of mixtures loaded on lateral surface by means of the Marshall apparatus according to ASTM (D1559). The optimum asphalt content (OPC) was founded to be (4.9%) according to Marshall method that is based on asphalt institute. Marshall Stability and Flow tests were performed on each specimen. The cylindrical asphalt specimen was placed in water bath at 60 °C for 30 minutes, and then compressed on the lateral surface at constant rate of (50.8mm/min) 2in/min. until the maximum load (failure) was reached. The maximum load resistance and the corresponding flow value were recorded.

6.2. Wheel Tracking Testing (rutting)

Wheel track test is used to determine the strength of hot mix asphalts against the permanent deformation at the critical temperature and under the loading similar to what is applied in the roads to the pavement surface. Wheel track test using sweep move of loaded wheel on the asphalt samples determines the rutting potential of asphalt pavements. The Pavement Wheel Tracker is a device for testing the workability of asphalt mixes by simulating roadway conditions. The test provides information about the vertical displacement from a moving, concentrated load. It uses a Linear Value Displacement Transducer (LVDT's) to measure the rut depth of the specimen. The weight wheel applies about 700 N (158 pounds) of load at contact points and passes repetitively over the asphalt sample for up to 1,000 cycles. If the maximum allowed deformation is reached before 1,000 cycles, the wheel will lift off the failed sample. Test results are compiled in programmed lab view package installed on desktop computer to read, log, and control data transferred from data acquisition at specified rate of frequency shown in Fig. 2 (Read and Whiteoak, 2003) and (Bodin et al., 2009). In this research, three temperature levels plus three stress levels were examined to simulate special local climate in Iraq, also development of new vehicles which classified as heavy load vehicles was the main reason for testing at three stress levels. Besides what mentioned previously, different aggregate gradations were investigated in addition to durability tests were also included.

Fig. 2: Photo of Wheel Track

6.2.1. Effect of Temperature

In this paper, the effect degree of temperature conditioning was evaluated using air temperatures of 40°C, 50°C, and 60°C to simulate the worst conditions of actual climate for pavement during the year in Iraq. Effect of temperature conditioning on mixture rut depth is illustrated graphically in Fig. 3.

Table 4 includes the effect of temperature rising from 40°C to 50°C and 50°C to 60 °C on rut depth that was evaluated for wearing mix. It is clear that increasing temperature conditioning resulted in a higher rut depth since it is believed that increasing temperature led to increasing binder viscosity, which cause a significant reduction in mechanical interlock bonding between aggregates components and bituminous binder, and therefore rut depth was increased for both mixes.

Temperature increase from 40 °C to 50 °C will increase in rutting by 57.65%. Also, increasing in temperature from 50 °C to 60 °C will increase rutting by a factor of 17.844 %. Albayati said that when the heat goes up from 20 °C to 40 °C the permanent deformation becomes higher by a factor 4.8, while an increasing from 40 °C to 60 °C causes higher factor that equals 5.13. (Albayati, 2006).

Table 4. Percentage of Change in Rutting with Temperature of Two Mixtures.

Temperature Increase, °C		Increasing Factor in Rutting %
From	**To**	
40	50	57.65
50	60	17.84

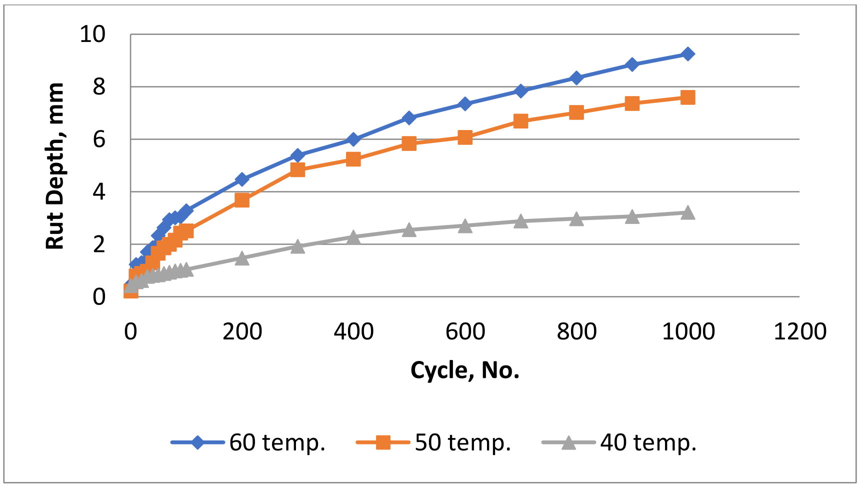


Fig. 3. Effect of Temperature on Rutting.

6.2.2. Effect of Stresses Levels

Three stresses levels were preformed: 700 N, 900 N, and 1100 N. It was noticed that increasing stress value from (700 to 900) N led to increase rutting by 40.75%. Also, increasing in stress value from (900 to 1100) N will increase rutting by 29.08%. (Abed, 2010) stated that permanent deformation results for asphaltic wearing coarse mixes when the stress increased from 10 psi to 20 psi and 20 psi to 27 psi will cause permanent deformation increases by 19 % and 29 %, respectively.

Table 5 shows the summary of these results. Fig. 4 illustrates the effect of different stress levels rut depth of asphalt mixtures.

Table 5. Percentage of Change in Rutting with Stress of Two Mixtures.

Stress Level, N		**Increasing Factor in Permanent Strain %**
From	**To**	
700	900	40.75
900	1100	29.08

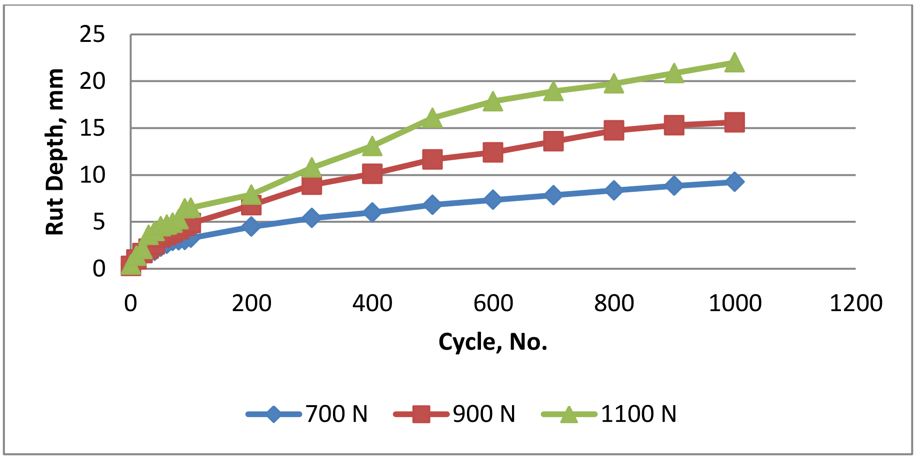


Fig. 4. Effect of Stress Value on Rutting.

6.3. Pneumatic Repeated Loads Testing

For each specimen, the numbers of load repetitions (N) were plotted against the permanent strain in log-log scale to find plastic parameter, for example, Fig. 5 represents (ε_p) versus (N) in log-log scale for (40-50) PG, at 40 °C, 30 psi stress value, and 4.9% asphalt content for surface mixture.

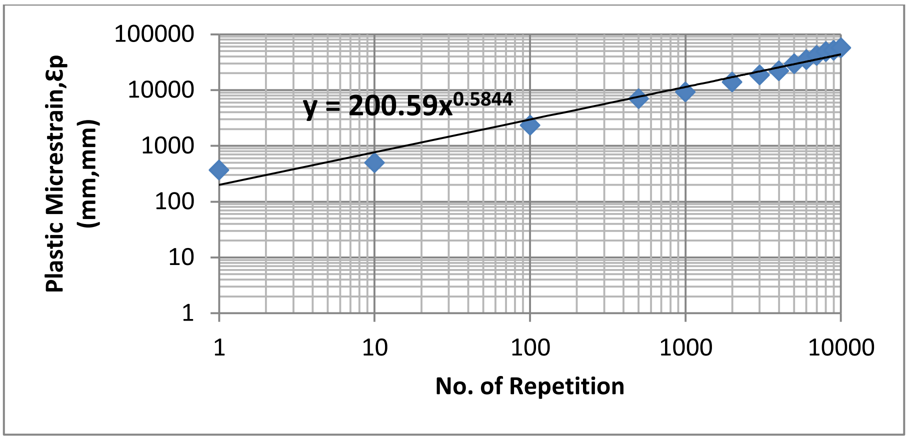


Fig. 5. Plastic Micro Strain Versus No. of Load Repetition.

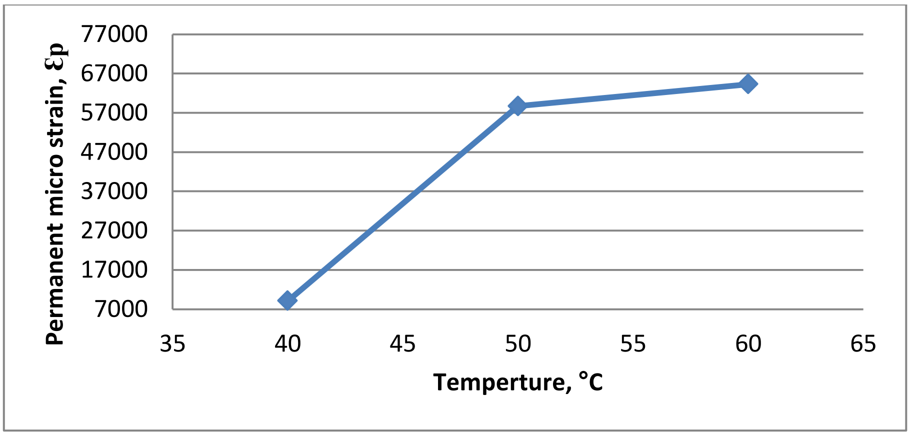
6.3.3. Effect of Temperature

Effect of temperature conditioning on permanent strain, elastic strain, and plastic parameters illustrated graphically in Fig. 6. It can be seen that permanent strain and resilient strain influenced when temperature changes from 40 to 50 °C more than changing from 50 to 60 °C.

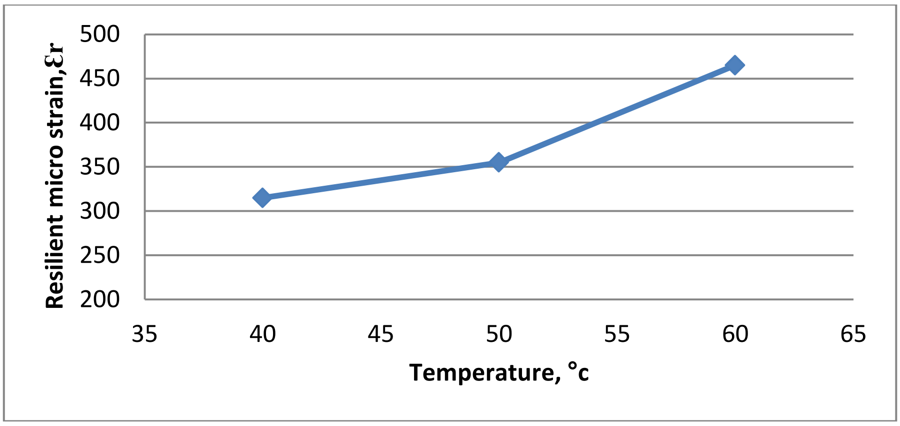
As shown in Table 6 when the temperature increases from 40 °C to 50 °C will increase the permanent strain and resilient strain by factor of 84.49% and 11.27%, respectively. Also, increasing temperature from 50 °C to 60 °C will increase the permanent strain and resilient strain by factor of 8.72% and 23.66%, respectively.

Table 6. Percentage Factors of Change in Permanent and Resilient with Temperature

Variables	Effect of temperature, %	
	40 to 50 °C	50 to 60 °C
permanent strain	84.49	8.72
Resilient strain	11.27	23.66



A: Effect of Temperature on Permanent Strain



B: Effect of Temperature on Resilient Strain

Fig. 6. Effect Degree of Temperature on Permanent strain and Resilient Strain.

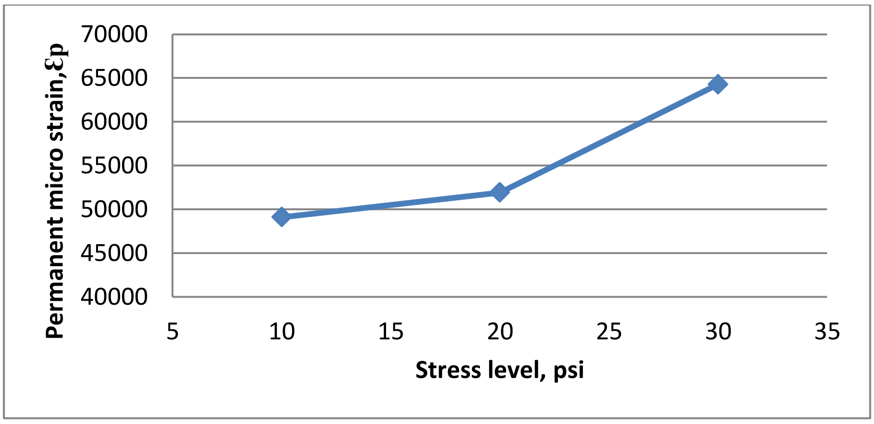
6.3.4. Effect of Stress Value

Three stresses levels were preformed are 10 psi, 20 psi, and 30 psi. It had noticed that Increasing stress value from (10 to 20) psi led to increasing permanent strain and resilient strain by 5.44% and 27.94%, respectively. Also, increasing the stress value from (20 to 30) psi will increase the permanent strain and resilient strain by 19.22 and 26.88%, respectively.

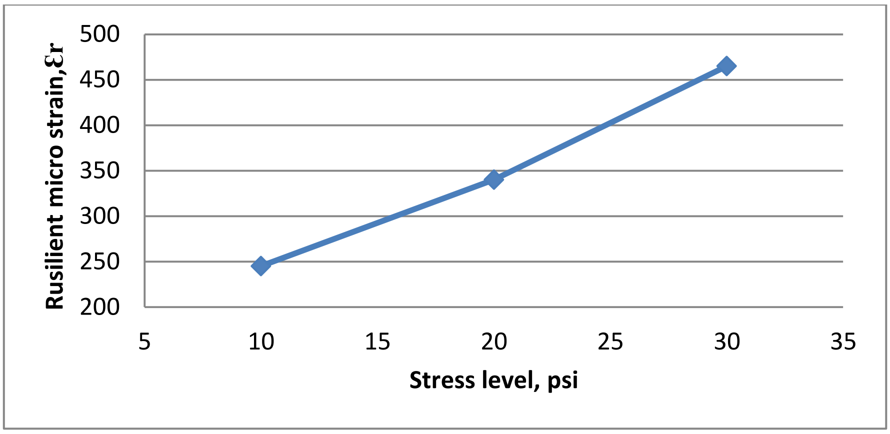
Table 7 shows the summary of these results. Fig. 7 illustrates the effect of different stress levels on elastic strain and plastic parameters of asphalt mixtures.

Table 7: Percentage Factors of Change in Permanent Strain and Resilient Strain with Stress Value

Variables	Effect of stress value, %	
	10 to 20 psi	20 to 30 psi
permanent strain	5.44	19.22
Resilient strain	27.94	26.88



A: Effect of Stress level on Permanent Strain



B: Effect of Stress Level on Resilient Strain

Fig. 7. Effect of Stress Level on Permanent Strain and Resilient Strain.

7. CONCLUSIONS

Based on the data results discussed previously in this research, the following conclusions can be drawn:

1. In term of wheel truck test, increasing conditioning temperature from 40 °C to 50 °C resulted in rutting increment by about 57.65%. While rising temperature from 50 °C to 60 °C led to increment for about 17.84% for wearing layer. Also, increasing load intensity from 700 to 900 N resulted in higher rutting values that increased by 40.75% for wearing layer. While increasing load from 900 to 1100 N under constant temperature led to increase rut depth about 29.08% for wearing layer.

2. In term of uniaxial repeated load test, increasing temperature from 40 °C to 50 °C resulted in permanent strain and resilient strain increment value about 84.49 % and 11.27 % for wearing layer. While rising temperature from 50 °C to 60 °C led to increment 8.72% and 23.66% wearing layer. Also, increasing load intensity from 10 to 20 psi resulted in higher permanent strain and resilient strain values about 5.44% and 27.94%, respectively for wearing layer. While increasing load from 20 to 30 psi under constant temperature led to increase the permanent strain and resilient strain to about 19.22 % and 26.88 %, respectively for wearing layer.

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