# Effect of rubber on dynamic creep of asphalt concrete mixtures


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**ABSTRACT:** The main objective of this research is to determine the effect of rubber on dynamic creep of asphalt concrete mixtures. Rubber was used as an additive to the asphalt concrete mixtures at five contents: (0, 5, 10, 15 and 20%) by volume of binder. Then, they were exposed to simulation of creep test through Universal Testing Machine (UTM). Three testing temperature levels (5, 25 and 40°C) simulating cold, moderate and high temperatures were considered. Three loading frequencies (1, 4 and 8 Hz) were used. Rubber is pollutant byproduct of used tires. This research attempts to recycle rubber by using it as an additive for asphalt concrete mixtures. Furthermore, the use of rubber decreases the economic cost of asphalt mixture constructing. Finally, it was found that the addition of an optimum percentage of (10%) of rubber increased the quality and performance of asphalt concrete mixtures by reducing rutting.


## INTRODUCTION

Asphalt cement is mixed with aggregate to produce asphaltic concrete mixtures, which are used in flexible pavement construction of highways, airports, and parking lots. These mixtures must provide acceptable level of flow, stability, air voids, and voids in mineral aggregates (VMA). Unfortunately, field observations indicated that many problems appeared in those pavements like permanent deformation, fatigue cracking, bleeding, raveling and so on. For this reason, addition of a variety of additives to the asphalt mixtures to produce new mixtures having new properties is normally called modifying bituminous mixtures.

Rubber powder has been used as an important additive to bituminous mixtures since 1930 (Kallin 1967). It has been used for a number of years by two methods, wet method as a part of binder and dry method as a part of aggregate to improve certain properties such as stiffness, flexibility, and permanent deformation of asphalt concrete mixtures (Roberts et. al.1990). Another reason for using rubber in the mix is to reduce environmental pollution and paving material costs (Kallin 1967).

Khedaywi et al (1994) studied the effect of rubber concentration on properties of asphalt concrete mixtures. One type of rubber was obtained by chopping the tread peel from scrap truck tires; asphalt cement (80/100) and crushed limestone aggregate were used. Four concentrations of rubber (5, 10, 15 and 20) percent by total weight of asphalt – rubber mixes, and three rubber particle sizes (No. 16-20, No. 20 -25 and No. 50 -200) were used. It was found that modifying binder with rubber reduced penetration, ductility, flash point, and specific gravity. They also found that the softening point increased with increasing rubber concentration in the binder. Results indicated that the stability decreased and flow increased with the increase in rubber content in the mixtures. Finally, they found that voids in mineral aggregates (VMA) increased with increasing rubber content in the binder.

Malpass and Khosla (1994) studied the rubberized mixtures in terms of resilient modulus, creep and fatigue. They designed the rubberized mixtures using Marshall and Gyratory testing machine (GTM). Granite aggregates, angular with smooth texture rubber and asphalt cement grade (AC – 20) were used. Both wet and dry processes were used. The extender oil and reaction catalysts were added at 2 and 7 percent by total weight of binder. They found that using GTM to predict the compaction stability of the mixture was more suitable for the design of rubber mixture than the modified Marshall procedure. They also found that the fatigue models developed for the mixture suggested that the rubber mixtures were more resistant to fatigue cracking and creep. On the other hand, models suggested that the permanent deformation performance over the wet and conventional mixtures were similar.

Roberts and Litton (1987) studied the effect of rubber on asphalt cement mixtures. They used surrounded river gravel and limestone aggregates with two types of binder: asphalt – rubber and conventional asphalt binder. In the case of asphalt rubber binder, a two-percent content of rubber by weight of binder was used. Asphalt cement type AC-10 was used. Optimum binder content was 5.5 percent by weight of aggregate. Marshall method was used to prepare and compact the specimens. Three compaction temperatures (275$^{o}$F, 325$^{o}$F, and 373$^{o}$F) and three levels of blows per face (25, 50, and 75 blows) were used. Marshall stability, Hveem stability, resilient modulus and air voids were evaluated on all specimens. The results of the tests showed that compaction temperature had significant influence on Marshall stability. Hveem stability was found to be fairly insensitive to temperature and number of blows. Air voids content was found to be fairly sensitive to both temperature and number of blows. The resilient modulus was found to be less sensitive to the compaction temperatures.

Khedaywi and Abu – Orabi (1989) studied the effect of rubber ash on asphalt cement properties. They used contents of 0, 5, 10, 15 and 20 percent of rubber – ash by volume of binder. They concluded that the softening point and specific gravity increased by increasing percentage of rubber ash. On the other hand, penetration and ductility were decreased with the increase of rubber ash content.

In this study, wet method will be used and dynamic creep test will be carried out to evaluate the effect of rubber on dynamic creep of the mixtures.

## OBJECTIVES

The main objectives of this research were as follows:-

i. To study the effect of rubber on dynamic creep of asphalt concrete mixtures.
ii. To investigate the feasibility of using rubber as an additive to the asphalt paving mixtures to achieve economic advantages and good performance.
iii. To find the optimum concentration of rubber which would give the best properties of asphalt concrete mixtures.

## MATERIALS USED

The materials used in this research are:

*Aggregate*

One type of limestone aggregate was used, which was brought from Wadi Al-Katar queries in Amman – Jordan. Gradation type was used according to the Ministry of Public Works and Housing (MPWH) (2010) specifications in Jordan. Table 1 shows the aggregate gradation and Table 2 summarizes the aggregate properties used in this research.

Table 1 Aggregate gradation

| Sieve size | Specification limits (% Passing) | % Passing (midpoint) |
|---|---|---|
| 1" (25mm) | 100 | 100.0 |
| ¾" (19mm) | 90 -100 | 95.0 |
| ½" (12.5mm) | 71 - 90 | 80.0 |
| 3/8" (9.5mm) | 56 - 80 | 68.0 |
| No.4 (4.75mm) | 35 - 56 | 50.0 |
| No.8 (2.35mm) | 23 - 49 | 36.0 |
| No.20 (850µm) | 14 - 43 | 28.5 |
| No.50 (300µm) | 5 -19 | 12.0 |
| No.80 (180µm) | 4 -15 | 9.5 |
| No. 200 (75µm) | 2 - 8 | 5.0 |

Table 2 Aggregate properties

| Aggregate Type | ASTM Test Designation | Bulk Specific Gravity | Apparent Specific Gravity | Absorption (%) |
|---|---|---|---|---|
| Coarse | C 127 | 2.523 | 2.660 | 2.03 |
| Fine | C 128 | 2.488 | 2.702 | 3.89 |
| Filler | C 128 | 2.650 | 2.788 | 4.20 |

*Asphalt*

One penetration grade of asphalt cement (60-70) was used in this study. Asphalt was obtained from the Jordan Petroleum Refinery Company in Zerqa/Jordan, which is widely used in flexible pavement construction. Table 3 presents the physical properties of the used asphalt.

Table 3 Properties of asphalt

| Test | Methods | Result |
|---|---|---|
| Ductility, 25$^{o}$C ,cm | ASTM D 113 | 112 |
| Penetration, 25$^{o}$C,100g, 5 sec, 0.1mm | ASTM D 5 | 65 |
| Softening point $^{o}$C | ASTM D 36 | 48 |
| Flash point $^{o}$C<br>Fire Point $^{o}$C | ASTM D 92 | 315<br>320 |
| Specific gravity at 25$^{o}$C | ASTM D 70 | 1.017 |

*Rubber*

Rubber used in this study was produced by grinding the tread of scrap truck tires at ambient temperature. The rubber properties and gradation are shown in Tables 4 and 5.

Table 4 Rubber properties

| Properties | Methods | Results |
|---|---|---|
| Specific Gravity | ASTM D 792 | 0.985 |
| Water Absorption after 24 hr. | ASTM D 570 | Less than 0.5 % |

Table 5 Rubber gradation

| Sieve Size | % Passing |
|---|---|
| No 100 | 100 |
| No 200 | 22 |

## LABORATORY WORK

*Preparation of rubber-asphalt binders*

The following steps were followed in preparing rubber - asphalt binders:

i. Rubber was heated in a stainless steel beaker and maintained at a temperature between 145$^{o}$ C and 150$^{o}$ C.
ii. Asphalt cement was heated in an oven at a temperature of about 145$^{o}$ C
iii. The stainless steel beaker used for mixing was cleaned and kept in the oven at a temperature of about 145$^{o}$ C.
iv. The required amount of asphalt was weighed into the beaker; then, the amount of rubber required to yield the desired rubber/asphalt ratio was weighed.
v. The beaker was placed on a hot plate to maintain a constant mixing temperature. The mixing temperature varied between 140$^{o}$ C and 145$^{o}$ C.
vi. The laboratory mixer was used, and then placed so that the propeller was about 1.5 cm above the bottom of the beaker.
vii. The mixer was started, and mixing continued for 5 minutes at 1,600 RPM. During mixing, it was necessary to watch for any undesirable splashing, which might introduce small air bubbles into the mix by changing the position of the mixer's propeller within the mixing beaker; it was possible to stop the splashing.
viii. At the end of the mixing operation, the rubber - asphalt binder was mixed with the heated aggregate to prepare asphalt - rubber concrete specimens.

*Determination of Optimum Asphalt Content for Conventional Mixes*

To determine the optimum asphalt content for the mixture, the procedure illustrated by the Asphalt Institute MS-2 Manual (2008) and ASTM D1559 (2008) was followed as a part of this study. For each asphalt content (4.0, 4.5, 5.0, 5.5, and 6%), three specimens were tested for stability, flow, air voids, unit weight, and voids in mineral aggregate. The optimum asphalt content, which was the average of asphalt contents that met optimum stability, maximum unit weight, and 4 % air voids, was determined. The value of the optimum asphalt content was found to be 5.3 % by total weight of asphalt concrete mixture

*Dynamic Creep Test*

The dynamic creep test was conducted to evaluate the effect of rubber on pavement design. The test was performed using Universal Testing Machine (see Figure 1).The test was carried out according to British Standards Institute BS (1996).

Marshall specimens for one type of aggregate (limestone) at optimum asphalt content, rubber content of (0, 5, 10, 15, and 20 %), and 50 blows on each side were prepared. Specimens heights and weights were measured to calculate the unit weight of each specimen. The following steps were followed:

i. For each rubber content and temperature combination, two specimens were tested, while widths and diameters were measured.
ii. Specimens were placed in a cabinet for 24 hours at conditional temperatures of (5, 25, and $40^{O}$ C) before testing.
iii. Each tested specimen was placed in a jig between two stainless steel loading platens with the face in contact with the specimen. The grease lower platen was securely fixed to the load frame and the upper platen made contact with the loading system via a spherical seating. The load cell and LVDT were subjected to the specimen.
iv. The stainless steel plates were used to distribute the applied pressure uniformly on the surface of the specimen.
v. Each specimen was subjected to a conditional stress of 10 kPa for 120 second before specimen was loaded.
vi. Haversine loading was applied without impact and with loads varying between (0 and 100 kPa). Tests were conducted at temperatures of 5, 25, and $40^{o}$ C. At each temperature level, three frequencies were adopted (1, 4, and 8 Hz). The output of the test was computerized and edited, which made it printable.

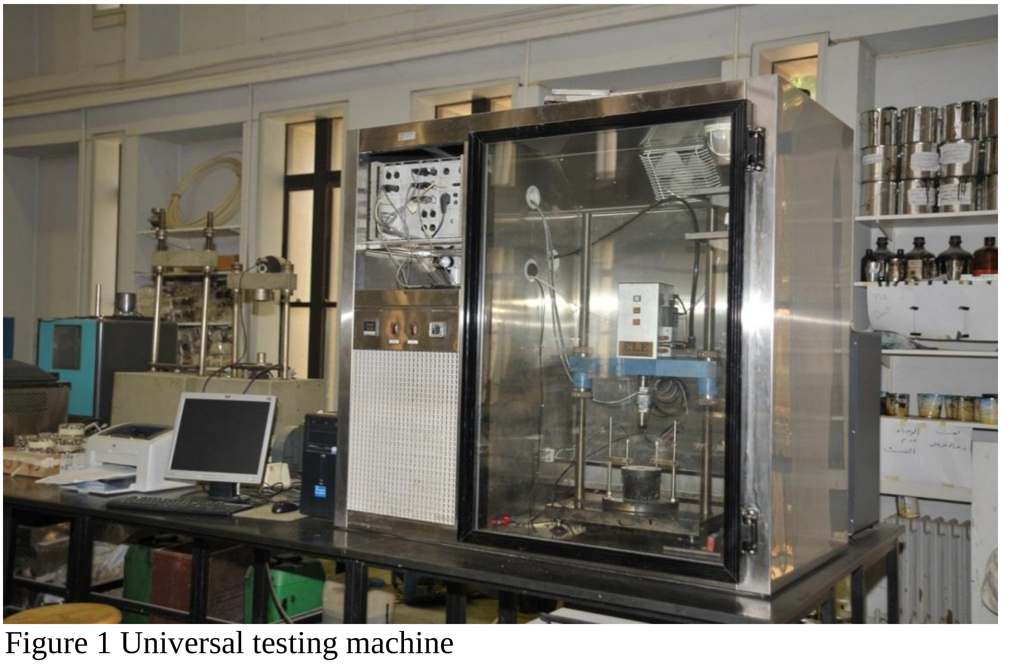

Figure 1 Universal testing machine

## RESULTS AND DISCUSSION

*Effect of Ash on Resilient Modulus of Asphalt Concrete Mixture*

Figures 2 to 4 present the effect of rubber on resilient modulus of asphalt concrete mixtures at different loading frequencies (1, 4, and 8 Hz) and at temperature levels of (5, 25 and $40^{o}$ C). The figures show that resilient modulus increased to an optimum value and then decreased with increasing rubber content. These figures also show that the optimum rubber concentration in the binder was 10% by volume of binder.

*Effect of Ash on Creep Stiffness of Asphalt Concrete Mixture*

Figures 2 to 4 present the effect of rubber on creep stiffness of asphalt concrete mixtures at different loading frequencies (1, 4, and 8 Hz) and at temperature levels of (5, 25 and $40^{o}$ C). The figures in general show that the creep stiffness increased to an optimum value and then decreased with increasing rubber content. The figures also show that the optimum ash concentration in the binder was 15% by volume of binder.

*Effect of Ash on Accumulated Strain of Asphalt Concrete Mixture*

Figures 2 to 4 present the effect of rubber on accumulated strain of asphalt concrete mixtures at different loading frequencies (1, 4, and 8 Hz) and at temperature levels of (5, 25 and $40^{O}$ C). The figures show that the accumulated strain decreased with increasing rubber content.

*Development of Rutting Model from Dynamic Creep Test*

The study considered 5 levels of rubber, 3 temperatures, 3 load frequencies (Hz), and air voids. The model developed was as follows;

$$Rut = 0.238 - 0.059\ Rub - 0.072\ AV + 0.314\ Temp + 0.236\ Hz \qquad (2)$$

Where: Rut = Rut depth in (mm),
AV = Air void (%),
Rub = Rubber content (%),
Temp = Temperature (5, 25, and $40^{o}$ C), and
Hz = Load frequency (1, 4, and 8 Hz)

According to the previous equation; rutting potential of asphalt - rubber concrete mixtures decreases as the mount of rubber in the mixture is increased.

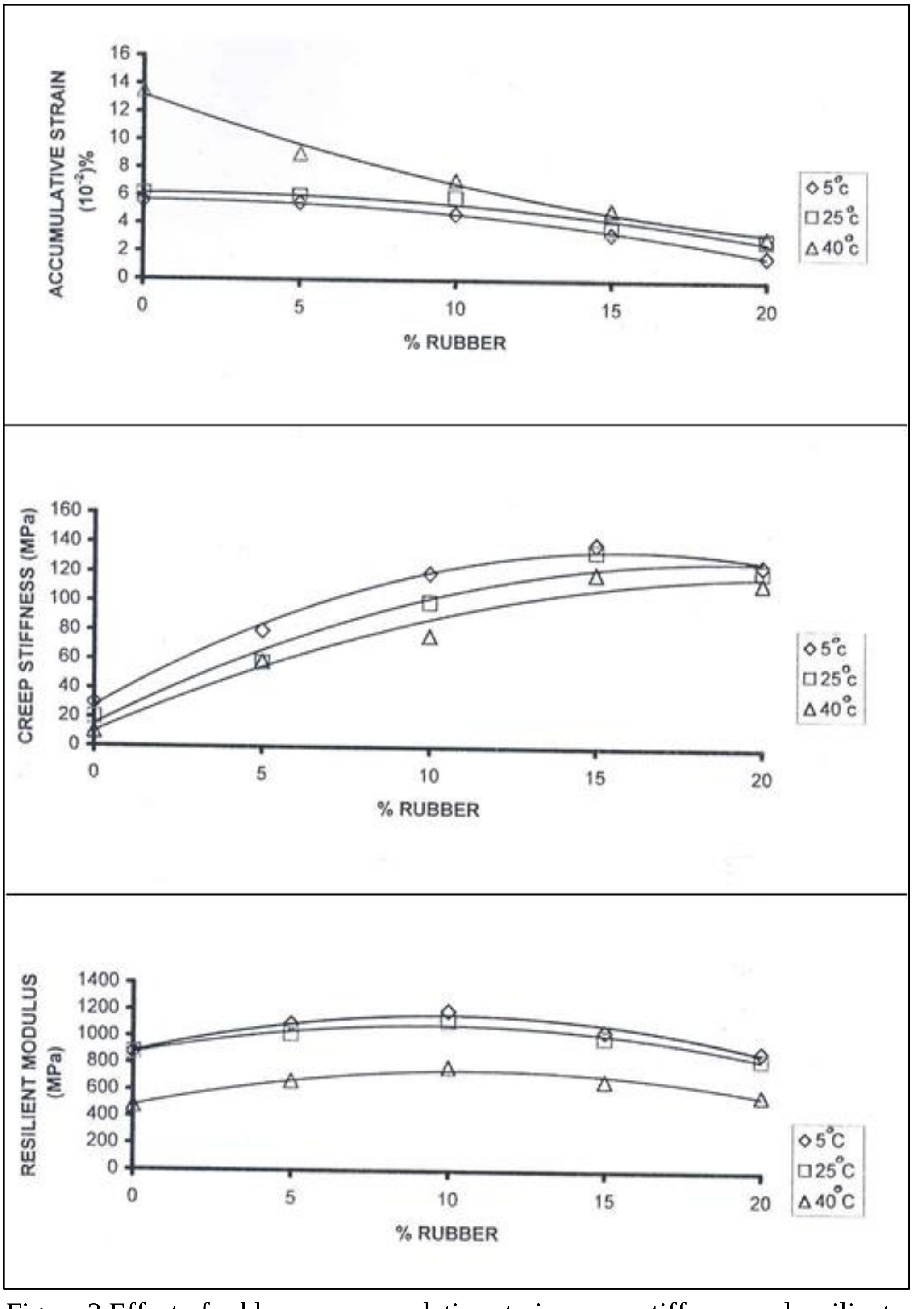


Figure 2 Effect of rubber on accumulative strain, creep stiffness, and resilient modulus for different temperatures at 1 Hz.

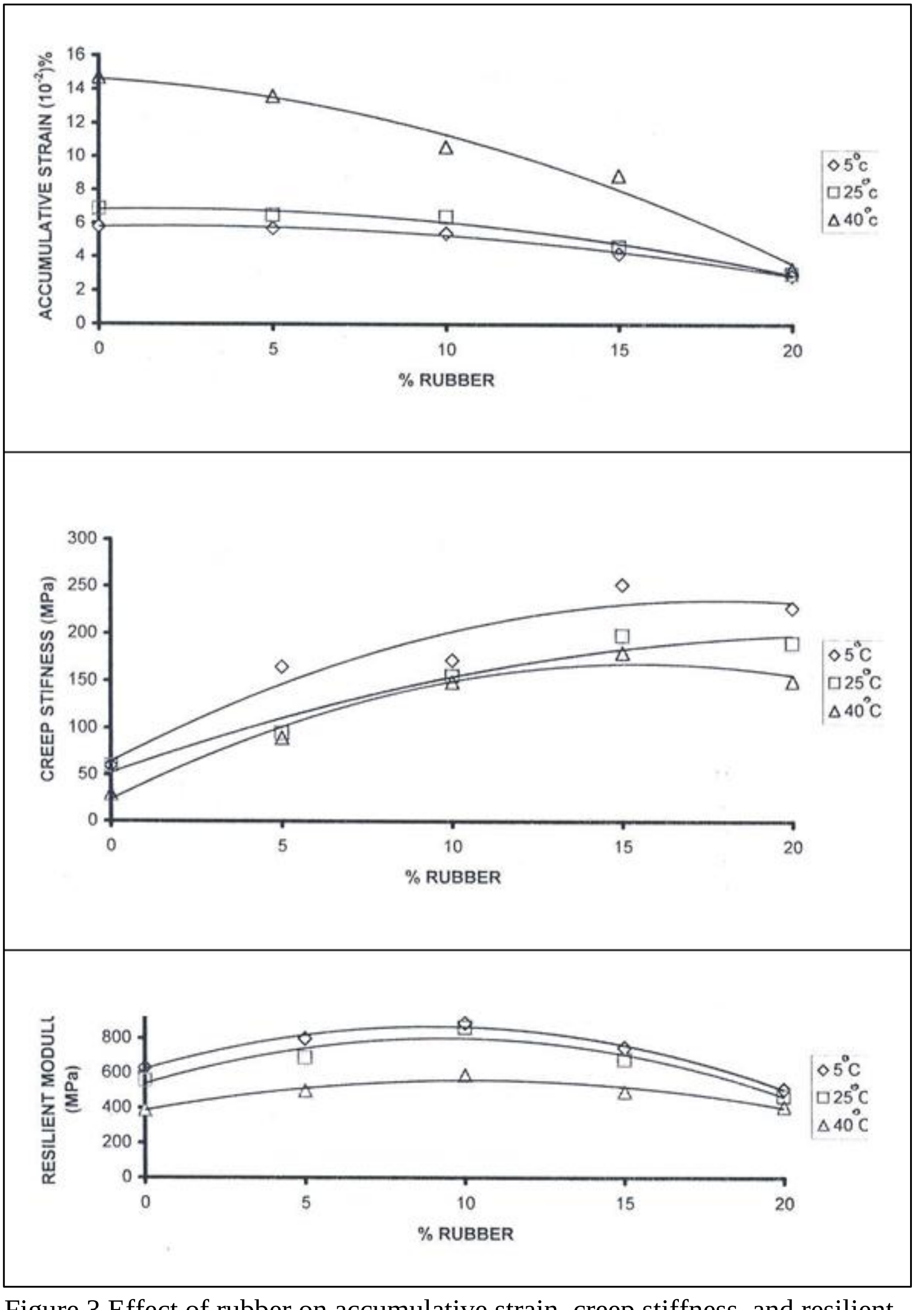


Figure 3 Effect of rubber on accumulative strain, creep stiffness, and resilient modulus for different temperatures at 4 Hz.

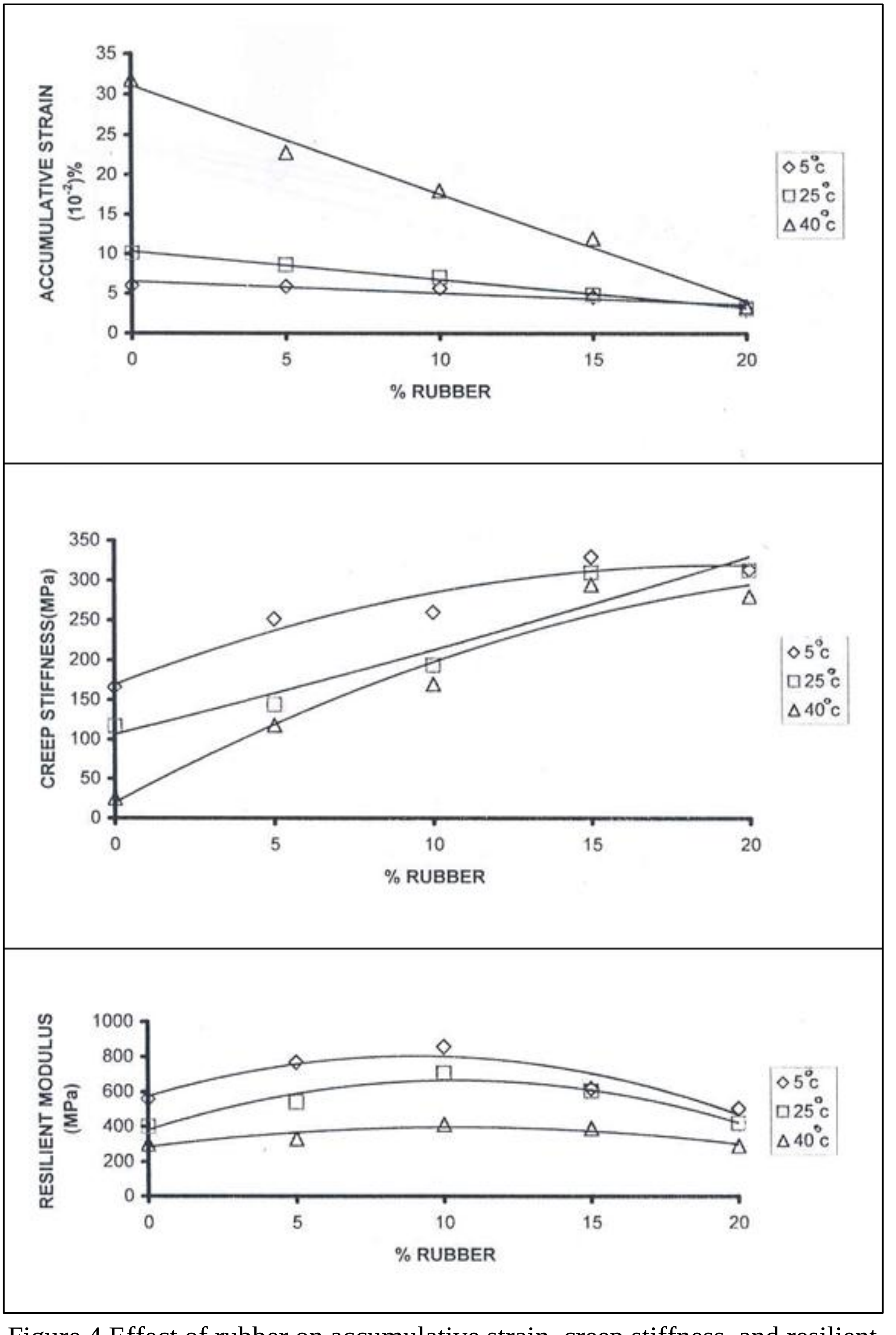


Figure 4 Effect of rubber on accumulative strain, creep stiffness, and resilient modulus for different temperatures at 8 Hz.

## CONCLUSIONS

The following conclusions are drawn from this research:

i. The 10 and 15% of rubber improves the resilient modulus and creep stiffness of bituminous mixtures, respectively, as it increases the adhesive forces between asphalt and aggregate.
ii. Temperature has a significant effect on resilient modulus and creep stiffness. As temperature decreases resilient and stiffness modulus increase.
iii. Loading frequency (Hz) has a significant effect on resilient modulus and creep stiffness. The maximum resilient modulus, creep stiffness and accumulated strain were obtained at 8 Hz, because the numbers of loading and unloading per unit time are more than that for the other frequencies (1 and 4 Hz)
iv. Accumulated strain increases as the temperature and loading frequency increase.

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