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Effect of Irradiated Crumb Rubber on Cold Recycled Bitumen Emulsion Mixes Properties

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Abstract

Recycling is one of the most innovative and interesting techniques for the rehabilitation of distressed road pavements. In recent years the increased interest in this process has led to the development of various alternative methods for the recovery and the reuse of road bituminous materials. Cold recycling is among the recycling techniques. Many researches involve the use of Crumb Rubber within a mixture containing 100% Reclaimed Asphalt Pavement. The goal of this research is to analyze and evaluate the different physical and mechanical characteristics from addition of irradiated crumb rubber to asphalt emulsion cold mixes. The results indicated that the existence of the irradiated crumb in asphalt emulsion could improve the indirect tensile strength, high temperature stability, moisture resistance and fatigue performance of asphalt emulsion cold recycled mixes.

***Keywords*:** Reclaimed; Asphalt Emulsion; Irradiated Crumb Rubber; Mechanical Characteristics**.**

1. Introduction

In recent years, policies of environmental sustainability in different social contexts has led to the implementation of new techniques and processes that are conducive to the more effective management of natural, economic, and energy resources. In this sense, there are many new techniques that contribute to a development that is more environmentally friendly (e.g. pavement recycling, use of waste material in bituminous mixes, low-temperature mixes that reduce emissions etc.) [1–8].

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These techniques aim to reduce the use of virgin raw materials and to promote the recycling and reuse of the so-called secondary raw materials (materials which, after complete initial use, may be used repeatedly in production as starting material). An ever increasing number of innovative and environmentally friendly materials have been launched on the market, and others are still under study, with the step of characterization of the materials of crucial importance. In the field of road engineering, the use of recycled materials has become important because of the limited availability of aggregates and the difficulties and excessive disposal costs for milled materials [9]. Several studies have been carried out regarding the assessment of the performance of asphalt mixtures with incorporation of crumb rubber obtained from recycled tires in the lab [10-11] or in the field [12], either using the wet process [10 - 11] or the dry process [13-15]. Other studies were performed to evaluate the use of crumb rubber in reclaimed asphalt pavement (RAP) mixtures [16] or to assess the acoustic performance of asphalt rubber (AR) mixtures [17]. The addition of crumb rubber to virgin bitumen [18] produces binders with improved resistance to rutting [10], fatigue cracking, and thermal cracking while allowing a reduction on the thickness of asphalt overlays and reflective cracking potential [19-20], possibly with the use of specific additives [21]. However, the production temperatures of the resulting AR mixtures are usually very high [22]. Thus, this type of mixture is a potentially successful application of the warm mix asphalt (WMA) technology, as has recently been object of study [23-24]. The use of radiation in the processing of polymers is gaining more and more interest because it can be suggested as an alternative to the traditional chemical methods to modify the molecular structure of polymers [25]. Several methods have been used to improve the microstructure of crumb rubber surface. [26]. improves the viscoelastic nature of CRMB by Microwave irradiation of crumb rubber surface method that cleft the surface of the vulcanization network, giving crumb rubber higher surface activity [27].

2. Materials and Methods

2.1. Materials

- Local asphalt of penetration grade 60/70, produced by El-Nasser Petroleum Company Suez - Egypt was used. The physical properties of this asphalt are listed in Table 1.
- Crumb rubber was kindly provided by Narobine Company, Cairo, Egypt, of particle size 10 meshes from the sidewalls of passenger tire. It contained approximately hydrocarbon, 59.8% (30% NR, 40% (SBR), 20%-NBR and 10% butyl and halogenated butyl rubber), 24% carbon black, 15% acetone extract, approximately 0.92% sulfur and approximately 0.98% Zn O. It is free from steel, fibers and any foreign containment in the rubber tire.
- Coarse and fine aggregates used in this investigation are complying with Egyptian Standard Specification E.S.S 1109/1971. Physical properties of the aggregates are shown in Table 2. The aggregates were dried and sieved as per BS EN 933-1 [28] to achieve the required gradation. Aggregate gradation for surface course is shown in Table 3.

2.2. Methods of Preparation

- Gamma irradiation activation method

In order to provide a chemical bonding between bitumen and polymer modifier, gamma irradiation method was applied to the LDPE [29].

Table 1: Properties of asphalt binder

Test properties	Unit	Asphalt 60/70
Penetration (25 °C, 100 g, 5 s)	0.1 mm	63
Softening point	°C	51
Ductility (25 °C, 5 cm/min)	cm	+ 100
Viscosity (60 °C)	poise	1569
RTFO aged asphalt residue		
Mass loss	%	− 0.04
Penetration ratio for asphalt residue (25 °C)	%	68
Ductility for asphalt residue(25 °C)	cm	+ 100

Table 2: Physical properties of the aggregates

Material	Property	Value
Coarse aggregate	Bulk particle density, mg/m^3	2.79
	Apparent particle density, mg/m^3	2.83
	Water absorption, %	0.6
Fine aggregate	Bulk particle density, mg/m^3	2.68
	Apparent particle density, mg/m^3	2.72
	Water absorption %	1.6
Mineral filler	Particle density, mg/m^3	2.71

Table 3: Aggregate gradation for surface course

Sieve size, mm	20	14	10	2	0.5	0.25	0.063
% Passing (specification range)	100	98-100	42-63	40	19-31	9-13	6
% By mass (passing mid)	100	99	52	40	25	20	6

Gamma irradiation method is used in several applications such as food processing, cancer treatments, and some sterilization systems. Gamma irradiation is electromagnetic of high frequency and rays are ionizing radiation. It provides a reformed chemical composition of the materials exposed to decay that might contribute to creating strong bonds between polymer modifier and bitumen. The irradiation source was an electron accelerator complex electric device, where the transition from regimes of treatment with charged particles (electrons) to regimes of treatment with stream of gamma quanta of a wide range of energies is possible. Irradiation was carried out at the National Center for Radiation Research and Technology, Atomic Energy Authority, Cairo, Egypt. The samples of CR were subjected to gamma radiation (gamma cell type 4000 A, India), in air, at ambient humidity and temperature. The absorbed dose was 300 kGy at a dose rate of ≈ 4 kGy/h.

- Preparation of modified asphalt

Unirradiated and irradiated rubber samples of 300 kGy at percentage 10%, by mass of total binder blended with asphalt 60/70 to form different modified binders (CRM). The CR was gradually added to the 170 °C preheated asphalt and a mechanical and thermal energy was applied through a high-speed shearing and dispersing emulsifying machine at 7000 rpm and a heated plated controlling the asphalt binder mix temperature. This setup was continued for 60 min, were after it the modified asphalt rubber mix was removed from the plate and allowed to cool for further testing.

- Asphalt emulsion preparation

Emulsions are manufactured by passing hot asphalt and water containing emulsifying agents through a colloid mill under high pressure. The colloid mill produces extremely small (less than 5 -10 µ) globules of asphalt, which are suspended in water.

- Experimental design

The objective of this study is to analyze the influence of asphalt (penetration grade 60/70), crumb rubber (unirradiated and irradiated) on the mechanical performance of asphalt emulsion cold mixes. The bitumen content of the mixes was based on our previous study, which had specified optimal amounts of bitumen, according to the Marshall test [13]. The mix design of modified asphalt emulsion mixtures was prepared on the Marshall Method for emulsified asphalt aggregate cold mixture design. The aggregate, cement, pre-mix water and asphalt emulsion was blended using a laboratory mixer. Specimens were mixed utilizing a Hobart mixer shown in Figure 1.

For the immersion Marshall test, indirect tensile test and indirect tensile fatigue test, the loose mix was compacted into cylindrical specimens with a diameter of 100 mm and a height of 63.5 $^{\pm 2}$ mm using a compactor. The specimens were cured at room temperature for 24 h and prepared for the performance tests. There were three replicate specimens for each group. For the dynamic modulus test, the loose mix was compacted using a compactor to produce cylindrical specimens with a diameter of 150 mm and a height of 170 mm. The dynamic modulus specimen dimensions were 100 mm in diameter and 150 mm in height.

2.3. Test Methods

- Indirect tensile strength test

For the ITS test the EN 12697-23 was adopted. According to this standard, all the specimens were kept at a temperature of 25 °C in a climate chamber for 6 h before testing. A constant speed of 50 mm/min was applied until failure. The value of indirect tensile strength can be calculated by Eq. (1). Indirect tensile apparatus is shown in Figure 2

Figure1: hobart mixer machine

$ITS = 2\ Pult / \pi\ t\ d$ ………………………………………………………….. Eq. 1

Where: ITS (Indirect tensile strength, kPa), Pult (Peak load, N), t (thickness of the sample, mm, and d (diameter of the specimen, mm)

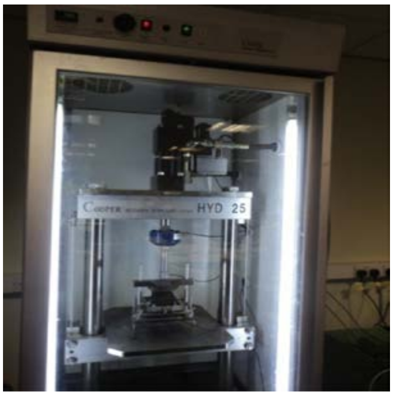

Figure 2: Indirect tensile apparatus

- Dynamic modulus test

The dynamic modulus test was conducted in a SPT testing system. According to AASHTO TP 62-03, dynamic modulus apparatus shown in Figure 3, a compressive stress was applied to the specimen to obtain axial strains between 50 and 150 micro-strains. Each specimen was subjected to loading frequency (25 Hz) at each of two temperatures (-10 and 50 °C). For each mix type, three replicate specimens were prepared for testing. The absolute value of the complex modulus, |E*|, is defined as the dynamic modulus, as shown in Eq. (2). The dynamic modulus |E*| is defined as the absolute value of the maximum stress (σo) divided by the peak recoverable axial strain (Ɛo) under a sinusoidal loading [30].

$E^* = \sigma_o / \varepsilon_o$ ………………………………………………….. Eq. 2

Figure 3: Dynamic modulus apparatus

- Fatigue test

Fatigue testing was performed in a four-point bending test apparatus shown schematically in Figure 4 and conducted as per BS EN 12697-24:2004 [31]. The vertical deflection at the center of the beam was measured using a LVDT situated at the top of the beam. The vertical deflection and the applied load were used to calculate the strains and stresses. Also, phase angle, dissipated energy and cumulative dissipated energy were calculated during the test. Prismatic samples with approximately 400 x 50 x 50 mm (length, wide and height) were prepared according to the mixing method and compacted by means of a static compaction using a compressive machine under a gradual application of 0.4 MPa/s static loads for 2 min. The full curing condition detailed earlier for samples was adopted. All tests were conducted at a temperature of 20 °C and 10 Hz frequency under sinusoidal loading with no rest period and controlled strain criteria of 150 µ strain. Fatigue failure has been arbitrarily defined as the number of cycles, Nf at which the initial stiffness is reduced by 50%.

- Wheel tracking test

The resistance of asphalt mixtures to permanent deformation (usually referred to as rut resistance), may be assessed by wheel tracking tests. The wheel tracking test involved the manufacture of two prismatic test specimens of 408 mm × 256 mm. Compaction was carried out by a roller compactor with a smooth steel roller to a thickness of 60 mm and a minimum density of 98% of the Marshall density. Two days after their compaction, both specimens were allowed to adjust to different temperatures of 25, 50 and 60 ± 1 °C, and then were tested at that temperature. The test itself involved the application of a load on the test specimen by means of the repeated passes of a loaded wheel. The load applied was 6.25 Kg and the number of passes was 1000, 2000 and 2500. Wheel tracking test apparatus shown in Figure 5

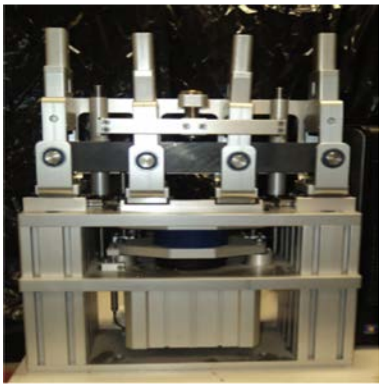

Figure 4: Four point load fatigue test configuration.

Figure 5: wheel tracking test apparatus

3. Results and Discussion

3.1. Indirect tensile strength test (ITS)

All the specimens were tested with the Indirect Tensile Strength test at 25 °C. Results are presented in Table 4. From the analysis of the histogram, it can be seen how the specimens conventional show greater ITS, while the mixture containing unirradiated rubber exhibit the lowest values. In particular, specimens with irradiated rubber showed an average reduction in strength of 13% compared to conventional mixtures. As for mixtures with unirradiated rubber their resistance values are reduced by 28%. These results clearly reflect the influence of the kind of crumb rubber used, in particular their different particle size. In fact, as already mentioned, the unirradiated rubber has a coarse gradation than irradiated rubber. This may negatively affect the meshing, and the consequent cohesion between the mixture constituents, resulting in a lower degree of compatibility and in a substantial reduction in strength for the unirradiated mixes. Specimens with irradiated rubber had higher strains than the unirradiated or conventional mixes. Higher strain indicates the mixes to be more ductility under tension. This characteristic is desired for mixtures to resist fatigue cracks.

Table 4: Effect of addition irradiated and unirradiated rubber on tensile strength

Temperature (°C)	Rubber types	Indirect tensile strength (MPa)	
		maximum stress at failure (MPa)	maximum strain at failure (%)
25°C	conventional	0.61	3.25
	Irradiated	0.53	4.95
	Unirradiated	0.44	4.12

3.2. Dynamic modulus test

The results of the dynamic modulus test are shown in Table 5. Irradiated rubber mixtures have better high temperature stability than conventional mixtures, Dynamic modulus for irradiated rubber mixtures increased between 15% and 42% compared to that of conventional mixtures at the same test condition. It can be concluded that the existence of the irradiated rubber in the reclaimed asphalt pavement could significantly improve the high temperature stability of asphalt emulsion cold mixes.

Table 5: Effect of addition irradiated and unirradiated rubber on dynamic modulus

Temperature (°C)	Rubber types	maximum dynamic modulus (MPa)
		maximum stress at failure (MPa)
- 10 °C	Conventional	5500
	Irradiated	7800
	Unirradiated	6200
50 °C	Conventional	2000
	Irradiated	2300
	Unirradiated	2120

3.3. Fatigue test

Fatigue test would terminate when the loading repetitions are more than 10,000 times, or the fatigue life is defined as the number of load cycles until the vertical deformation reaches 10 mm. The deviator stress 500 kPa and contact stress 25 kPa were adopted in the test. As shown in Figure 6, in consideration of the influence of the aged asphalt, fatigue life of unirradiated rubber mixes increased 43.7% compared to that of conventional mixes. As to the effect of irradiated rubber mixes, fatigue life increased 33.6% and 92% compared to that of unirradiated rubber and conventional mixes, respectively. The results indicated that the aged asphalt in irradiated rubber used as additive could improve the fatigue life of asphalt emulsion cold mixes.

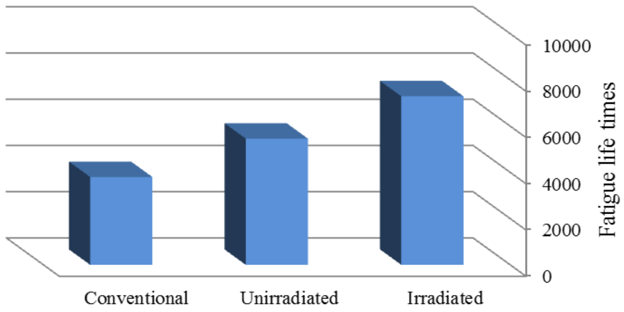

Figure 6: Effect of addition irradiated and unirradiated rubber on fatigue life.

3.4. Resistance to permanent deformation

The final rut deformation of the tests carried out on conventional, Unirradiated, and irradiated rubber mixtures are observed in Table 6, the main parameters obtained from this test are the final rut deformation at different temperatures. For a comparative analysis, the conventional mixture showed the higher susceptibility to deform permanently in the presence of high temperatures, while the irradiated mixture showed a better performance due to its significantly harder binder. Nevertheless, the Unirradiated additive was able to slightly improve the rutting resistance performance. Adding crumb rubbers to the bitumen caused increase in its stiffness and viscosity. Improving both of these features in bitumen can lead to increase the stiffness of asphalt mixtures and the rate of rut depth in them is considerably reduced. The results show that with increasing wheel passes, the values of rut depth either in modified specimens or in conventional is increased, but the rut depth growth with increasing wheel passes in the rubberized asphalt samples is less. This phenomenon occurs due to reducing the thermal sensitivity of asphalt mixtures affected by the addition of crumb rubber. Softening point of bitumen is greatly improved by addition of crumb rubber that this factor can lead to the reduction of thermal sensitivity of modified bitumen and thus asphalt rubber mixtures.

Table 6: Final deformation for conventional and rubberized asphalt samples

Temperature (°C)	Rubber types	Final deformation (mm)		
		1000 wheel passes	2000 wheel passes	2500 wheel passes
25°C	conventional	0.733	0.971	1.008
	Unirradiated	0.133	0.171	0.208
	Irradiated	0.331	0.475	0.501
	conventional	2.031	1.925	2.352

50°C	**Unirradiated**	**0.431**	**0.525**	**0.652**
	Irradiated	**0.708**	**0.953**	**1.229**
	conventional	**2.649**	**3.168**	**3.834**
60°C	**Unirradiated**	**0.649**	**1.368**	**1.634**
	Irradiated	**1.061**	**2.092**	**2.451**

4. Conclusions

In this paper, effect of addition irradiated and unirradiated rubber on the performance of asphalt emulsion cold mixes was investigated by means of the performance tests. Based on the laboratory results and analysis, the following conclusions have been drawn.

- The addition of irradiated crumb rubber to asphalt emulsion cold mixes had a significant influence on the mechanical performance of the mixes.
- Irradiated rubber had higher strains than the unirradiated or conventional mixes. Higher strain indicates the mixes to be more ductility under tension. This characteristic is desired for mixtures to resist fatigue cracks.
- In terms of stiffness modulus results, irradiated rubber in the reclaimed asphalt pavement could significantly improve the high temperature stability of asphalt emulsion cold mixes.
- The results indicated that the aged asphalt in irradiated rubber used as additive could improve the fatigue life of asphalt emulsion cold mixes.
- Irradiated waste rubber has high impact on reducing rut depth of asphalt mixtures at different temperatures and wheel passes.

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