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The Effects of Classifying CRM Sources on the Asphalt Cement Modification for Paving Roads

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Abstract

The improvement of Basrah asphalt cement that used in hot mix pavement can be achieved by using four influencing variables, which are the value of temperature needed for mixing, time of mixing, the amount of wasted car tire rubber (WCR) and the amount of wasted truck tire rubber (WTR). The main virtue of this study is to know the affecting of classifying the CRM sources, and how that will enhance the properties of tire rubber modified asphalt binder. The improvement is estimated through using the ranges (150-180 ^{o}C) of temperature, (20-60) minute of mixing time, (10-20) gm of WCR and (0-4) gm of WTR.

The using of two different types of waste tires had shown clearly the affecting on the results of responses studied. The effect of independent variables was studied by using Box-Wilson technique of experimental design. Moreover, the regression coefficients for responses models equation and the optimum conditions were estimated by using STATISTICA software.

The results had shown that the optimum values of the independent variables to submit the best responses of penetration test and softening point test was at temperature (180°C), mixing time (60 minute), WCR (20 gm), and WTR (4gm) and then found new mathematical models to estimate these responses at any values of independent variables. The Marshall stability result of the modified asphalt mixes was higher than of the unmodified asphalt mixes.

Keywords: Wasted car tires rubber WCR, Wasted truck tires rubber WTR, Asphalt cement AC, Preparation

1. Introduction

Millions of new tires are produced annually around the world according to the Tire Business Statistics (Michelin Fact Book) and this number increases every year according to wide needs for transportation vehicles, cars or trucks, in addition to other usages of tires. One scrap tire per one person was generated (Heitzman, 1992) according to the US studies which refers to the large number of waste tires that may reach approximately 900 million scrap tires every world wide (Way, G.B. et al. 2011).

Hence, millions of scrap tires become available for reprocessing into crumb rubber as an environmentally economical sound method of waste tires reduction (Carlson et al.1999). It is delivered to rubber processing plants either as whole tires, cut tires (tread and sidewalls), or shredded tires which are further reduced in size by ambient or cryogenic grinding of crumb rubber to produce crumb rubber ,the steel belting and fiber reinforcing are separated and removed. Crumb rubber cannot be considered as a waste material, it is proved that it is one of the only modifiers to pavement of roads derived from a waste material by recycling of scraped tires.

The proportion of the elastomer (natural and synthetic rubber (Caltrans ,2006)) varies according to the size and the use of the tire, cars or trucks,but in general the truck tire rubber contain larger percentage of natural rubber compared to that in car tire rubber (Williamson , 2006). In the present study, Basrah refinery asphalt cement is used.

Up till now, more of studies that used CRM as an additive for modifying asphalt cement (AC) without any classifying of CRM sources, wasted cars tires rubber or wasted trucks tires rubber, are: Abass et al., 2009, Aisien et al., 2006, Bahia et al., 2011, Carlson et al., 1999, Coomarasamy et al.,1997, Engle et al., 2002, Fayadh,S.S., 1987, Fonts et al., 2009, Ghaly,N.F., et al., 2008, Heitzman.M.A., 1992, Kumar et al., 2009, Neto et al., 2009, Papaiannakis et al., 1995, Pavlovich et al., 1978, Sousa et al., 2000, Williamson.P., 2006, Khodary.F, 2010. The present study aimed at investigating the benefit classification of CRM sources on the asphalt cement modification for roads pavement requirements.

2. Experimental Details

2.1 Experimental Apparatuses

The apparatuses that used in the present study to achieve the required results of using the classified CRM according to sources, as a benefit modifier are:

- Mixer apparatus consist of oil bath (model LABTECH / *Malaysia*, model LOB-511D), Mechanical stirrer type ANALIS / *Belgium*, Thermometer model QUICKFIT Corning / *England*, model MF32-C7/250 with a range of temperature is (0-250^{o}C), and Stainless steel containers.
- Penetration test apparatus (model ZHEJIANG TUGONG Instrument Co. /Japan, Serial No. 09108).
- Softening point apparatus (model TECHNOVERTO company)

- Electronic balance apparatus (model ADEM-USA).
- Water bath apparatus (model FREUNDL –Germany).
- Compactor apparatus (model VIATEST - EOH-Germany).
- Marshall (stability and flow) apparatus (model ELE international – England).

2.2 Specimen Preparation

The main materials that had been used in the current study are:

- Waste rubber had taken from disposal car tires WCR.
- Waste rubber had taken from disposal truck tires WTR.

The size of waste rubber used in the present study has to be finally ground equal or less than sieve No. 30 (specified sieve opening is 0.0232 inch or 0.6 mm) [6, 35, 36, 40] that some times called one size fine grading. The less difference in the size of waste rubber is refers to the difference in compositions ratios especially the actual and synthetic kinds of rubber in the recycled tire. The use of this finally size of rougher waste rubber will swell quicker and easily to absorb the asphalt cement.

- Aggregates that used are uniform quality and crushed to the size of coarse portion ranges from sieve (19.0mm) to sieve (4.75mm), while middle and fine portion of aggregates ranges between sieves (4.75 mm) to (0.075 mm). The reason of using crushed aggregates in the surface course is the mechanical interaction between the aggregates and the increment of the resistance to shoving because of the fraction action that increased between the coarser aggregates that all would lead to the high stability required.
- Mineral Filler that can be used according to ASTM-D242/ 2003 or AASHTO-M17/2010 .Where this additive physically increases the viscosity of asphalt cement to a limited range, which leads to more stability of the pavement layer and decreasing the effects of high ambient temperatures. This filler cans also decreasing the bleeding of excess asphalt cement used by absorbing this excess portion and then decreasing the porosity of the final pavement surface.
- Asphalt Cement that applied in the present study is supplied from Basrah refinery with the following specifications, which listed in Table (1) according to the specification of ASTM and AASHTO.

Table (1). Physical properties of asphalt cement selected

The Property	Unit	Test	Value
Specific gravity at 25 °C	gm/cm^3	ASTM-D-70 AASHTO-T-228	1.03
Flash point	°C	ASTM-D-92 AASHTO-T-73	275
Penetration at 25 °C	1/10 mm	ASTM-D-5	46

(100 gm, 5 sec, 0.1 mm)		AASHTO-T-49	
Softening point (ring and ball)	^{o}C	ASTM-D-36 AASHTO-T-53	48
Solubility in CCl_4 %wt. min.	%	AASHTO-T-44	99

The sequences of the experimental work can be summarized as follow:

- Preparing two enough amounts of the CRM according to the source of rubber which type wasted car tire car WCR and wasted truck tire WTR.
- Heating a limited amount of asphalt cement by using the oil bath in the Mixer apparatus until it reaches the restricted temperature then adding the restricted amounts of WCR and WTR, then keep mixing it for the limited known mixing time.
- Filling required measurement tools by limited amounts of the modified asphalt cement.
- Measuring the penetration responses, softening point responses, and Marshall properties (stability and flow).

3. Results and Discussion

3.1 The Mathematical Models

The coefficients of the second order polynomial will be estimated by using STATISTICA program according to the regression analysis rule for each of the responses that had been estimated experimentally. To emphasis the accuracy of the calculations, all the regression coefficients will be statistically, significant which means it will be estimated. The following models that estimated by using the non-linear estimation order are explained the relation between the response and the independent variables. Moreover, the temperature designed as X_1, mixing time designed as X_2, WCR designed as X_3 and WTR designed as X_4.

$$Y_{Penetration} = 432.983 - 4.947\ X_1 - 0.387\ X_2 - 1.220\ X_3 - 0.183\ X_4 + 0.016\ X_1^2 + 0.003\ X_2^2 + 0.041\ X_3^2 + 0.754\ X_4^2 + 2.703\ x10^{-9}\ X_1X_2 - 0.007\ X_1X_3 + 0.017\ X_1X_4 + 0.025\ X_2X_3 - 0.088\ X_2X_4 - 0.100\ X_3X_4 \quad (1)$$

The proportion of variance for the penetration was equal to (*0.97764*) and the correlation coefficient (R) was (*0.98870*), so the number of iterations will be terminated.

$$G_{Softening\ point} = 150.2499 - 0.7667\ X_1 - 0.1833\ X_2 - 1.3333\ X_3 - 22.0833\ X_4 + 0.0011X_1^2 - 0.0031\ X_2^2 + 0.0300\ X_3^2 + 0.563\ X_4^2 + 0.0033\ X_1X_2 + 0.0067\ X_1X_3 + 0.0833\ X_1X_4 - 0.0100\ X_2X_3 + 0.0250\ X_2X_4 + 0.4500\ X_3X_4 \quad (2)$$

The proportion of variance for the softening point response was equal to (*0.96846*) and the correlation coefficient (R) was (*0. 98411*), so the number of iterations will be terminated.

3.2 The Affecting of the Classified CRM on the Responses

In simple comparison depending on the mathematical models, the effect of classifying CRM in to types, WCR and WTR, is very clear. Table (2) explains this positive affecting on responses when using of WCR only or incorporate with WTR at optimum temperature and mixing time.

Table (2). The positive effect of using WTR for **AC** modification

The variable	Unit	The value (case I)	The value (case II)
Temperature	^oC	180	180
Time	min.	60	60
WCR	gm	20	16
WTR	gm	0	4
Penetration	mm	31.575	25.377
Softening point	^oC	58.820	72.860

The following figures are shown the effects of CRM sources classification:

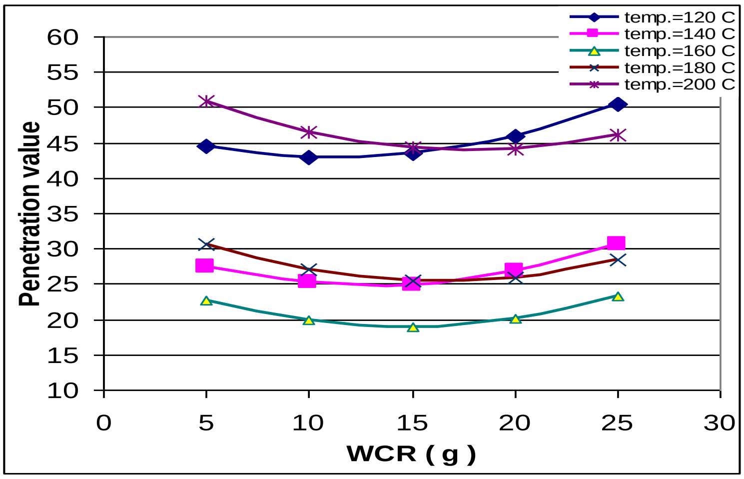

Figure (1). Penetration value as a function of WCR at optimum WTR & mixing time and various temperatures

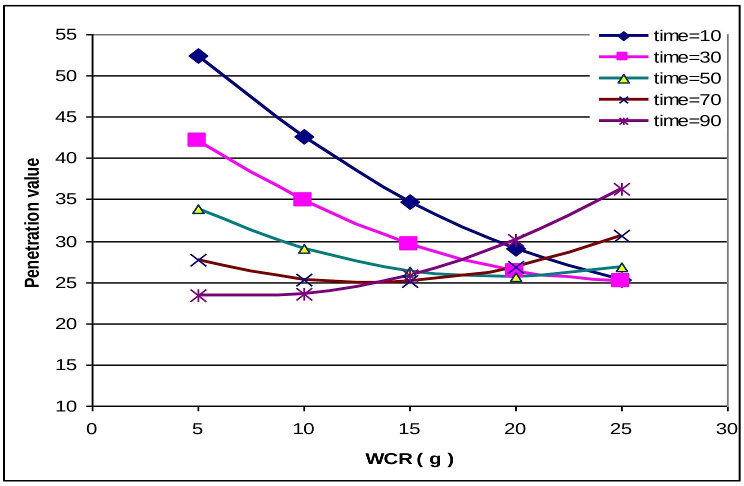

Figure (2). Penetration value as a function of WCR at optimum WTR & temperature and various mixing time

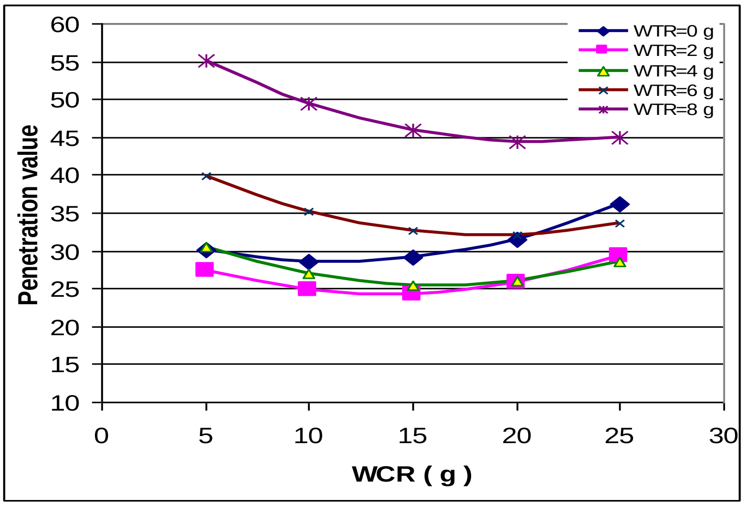

Figure (3). Penetration value as a function of WCR at optimum temperature & mixing time and various WTR

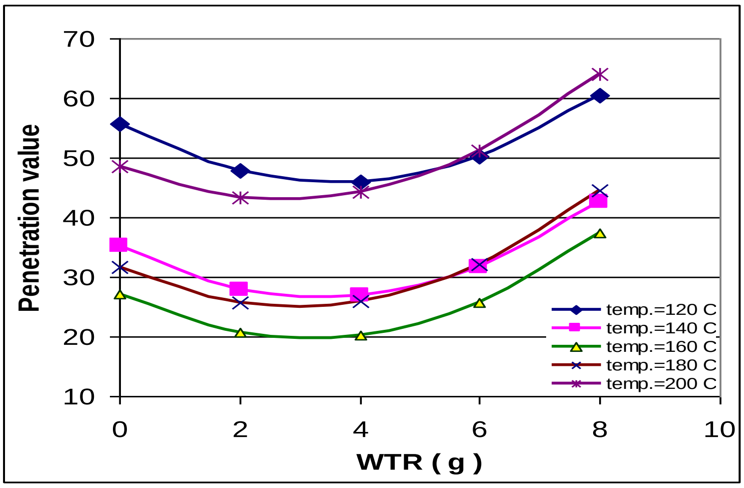

Figure (4). Penetration value as a function of WTR at optimum & mixing time & WTR and various temperatures

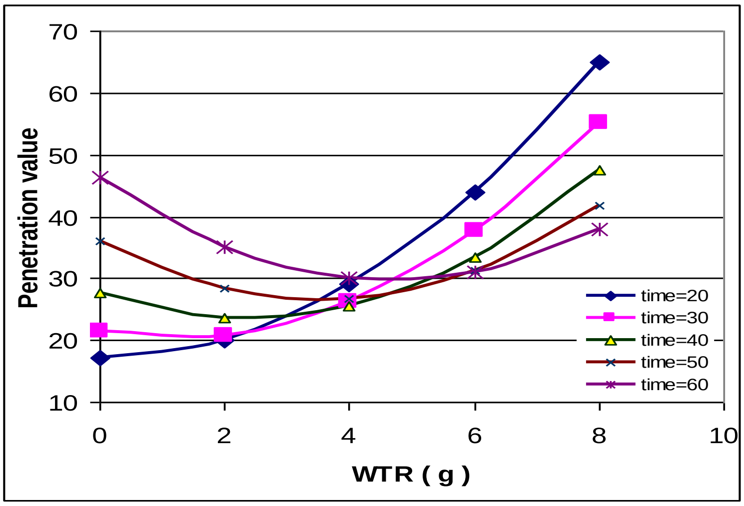

Figure (5). Penetration value as a function of WTR at optimum WCR & temperature and various mixing time

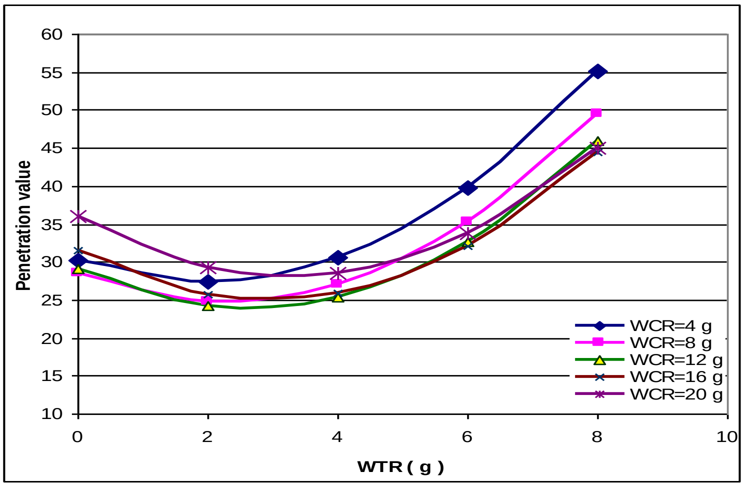

Figure (6). Penetration value as a function of WTR at optimum temperature & mixing time and various WCR

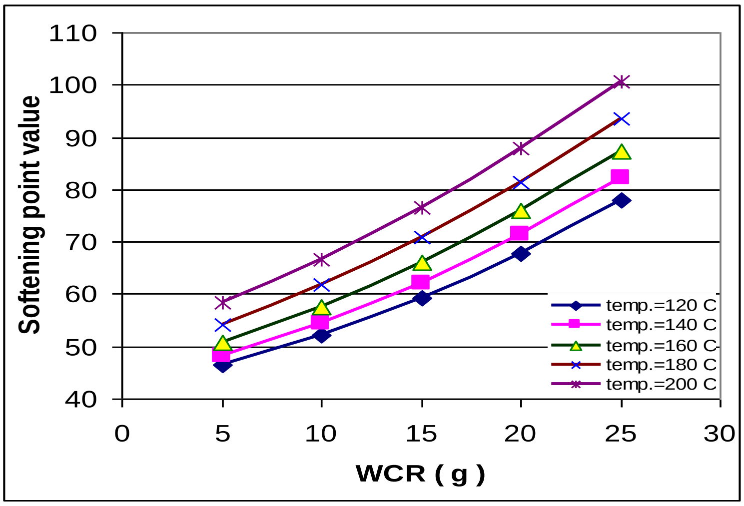

Figure (7). Softening point value as a function of WCR at optimum mixing time & WTR and various temperatures

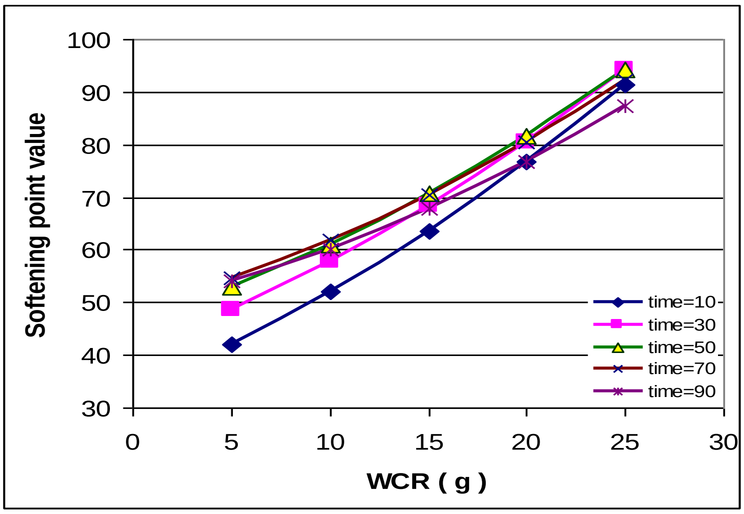

Figure (8). Softening point value as a function of WCR at optimum temperature & WTR and various mixing time

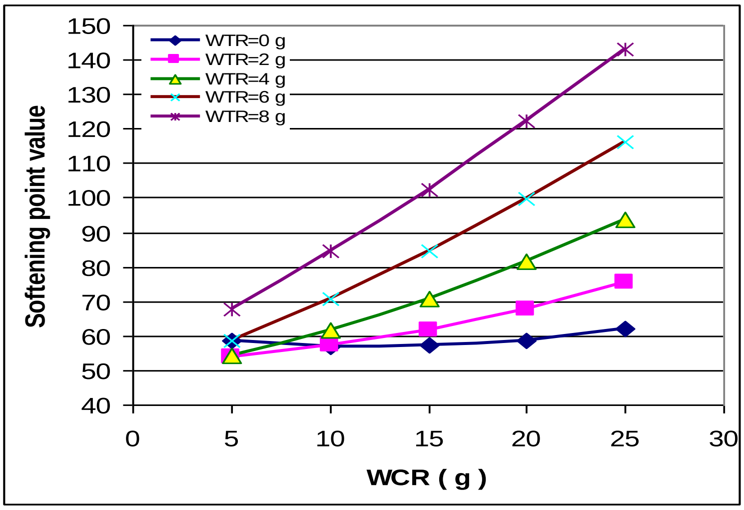

Figure (9). Softening point value as a function of WCR at optimum temperature & mixing time and various WTR

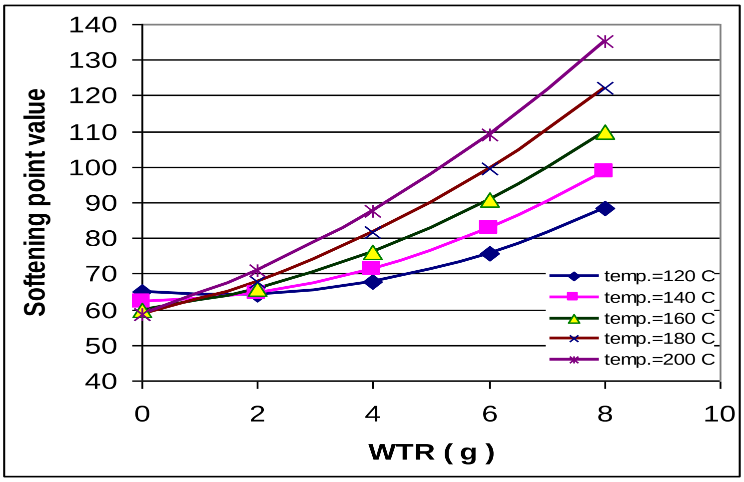

Figure (10). Softening point value as a function of WTR at optimum mixing time & WCR and various temperatures

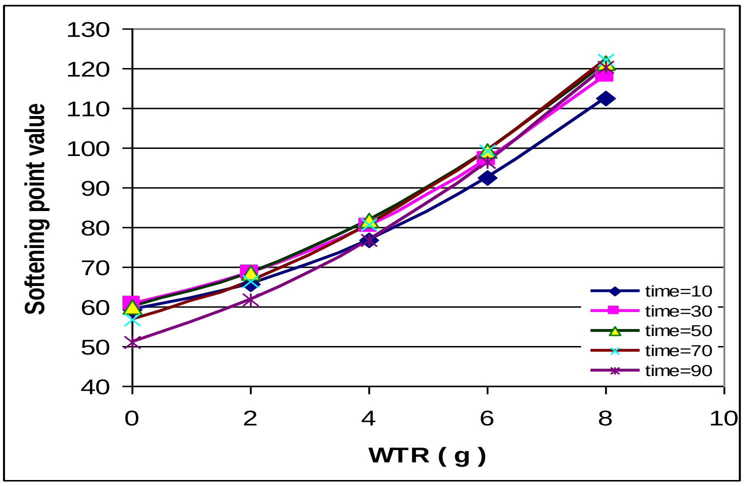

Figure (11). Softening point value as a function of WTR at optimum temperature & WCR and various mixing time

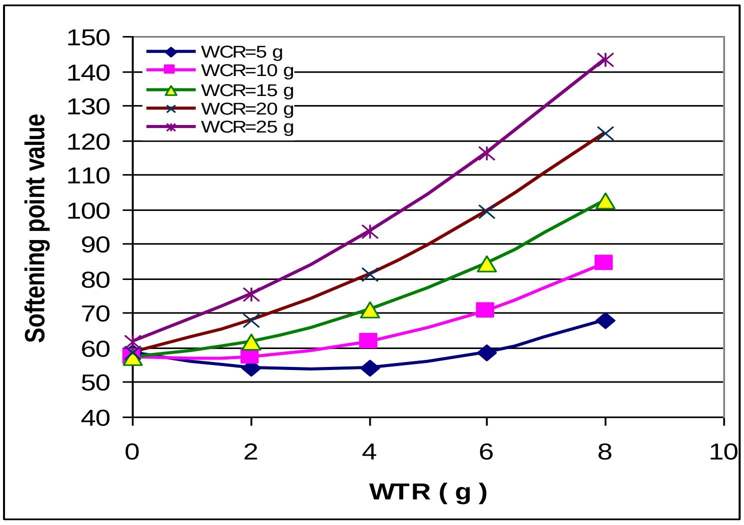

Figure (12). Softening point value as a function of WTR at optimum temperature & mixing time and various WCR

3.3 The Optimum Values

The optimum values of the four variables that correspond to desired value of each one of responses can be determined by following one of the optimization techniques according to the analysis of central composite (response surface) via STATISTICA software. Table (3) is shown the values and differences of optimized independent variables and the critical values for each of responses respectively.

Table (3). The optimum and critical values of the variables and their responses

Variables	Unit	Penetration (mm)		Softening point (^{o}C)	
Case		Optimum	Critical	Optimum	Critical
Temperature	^{o}C	180	159.48	180	199.04
Time	min.	60	61.20	60	68.24
WCR	gm	20	12.64	20	6.89
WTR	gm	4	2.75	4	0.61
Response's Value	---	25.933	17.786	81.471	55.611

The *Critical values* were estimated via STATISTICA software display the information that identify the point on the quadratic response surface that defines the curvature of the surface, which give the lower values of responses than the values that estimated at low limits of independent variables, it give an attention when the operation must be stop.

3.4 Results of Marshall Properties

By using the following tests to the measurement of resistance to plastic flow asphalt mixtures using Marshall apparatus.

- ASTM D 1559 – 2003
- AASHTO T 245 – 2010

Table (4). Mechanical and physical properties of the specimens using different ratio of Modified Asphalt Cement ***MAC***

Modified AC %wt.	*Bulk Volume*	F_{m1}	*Bulk Density*	*Specific Gravity*	*VTM %*	*VMA %*	*VFA %*	*Stability (KN)*	*Flow mm*
4	511.333	1.000	2.290	2.488	7.954	16.849	52.805	13.230	3.233
4.5	509.502	1.000	2.307	2.473	6.671	16.747	60.292	13.334	3.365
5	507.667	1.040	2.320	2.452	5.388	16.645	67.780	13.433	3.500
5.5	511.331	1.000	2.315	2.433	4.825	17.190	71.888	11.983	3.731
6	515.000	1.000	2.314	2.417	4.264	17.734	75.995	10.532	3.967

The properties of Hot Mix at the optimum value of *modified* asphalt cement (5.10 %) will be as shown in Table (5):

Table (5). Hot Mix properties at the optimum value of Modified AC

Modified AC %	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	VTM %	VMA %	VFA %
5.10	13.30	3.60	2.320	5.20	16.70	68.00
Specification Limits	8.00 minimum	2 – 4	-	3 - 7	-	-

While the Hot Mix properties for the same ratio but for *non-modified* asphalt cement, is explained in Table (6):

Table (6). Hot Mix properties at the optimum value of Non-Modified AC

Non-modified AC %	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	VTM %	VMA %	VFA %
5.10	9.60	4.50	2.445	3.10	14.10	78.20
Specification Limits	8.00 minimum	2 – 4	-	3 - 7	-	-

Therefore, Table (5) consists of the important values that will be the most cost-effective and efficient solution for the process in addition to maximum requirements and yielding the best value of the performance criterion for several types of roads (expressway, national roads, and other).

4. Conclusion

The following conclusions can be drawn from the present investigation:

- The using of waste tires is more useful for the modification of asphalt cement that produced from Basrah refinery to be more efficient for the requirements of roads paving in various climatic and traffic condition according to standard quality performance. However, waster tires rubber is too cheap and consuming it in this way will be beneficial from the engineering, economic, and environmental points.

- The using of two types of waste tires, car and truck tires,(i.e. classification of CRM sources) will be more affecting on the results that noted in penetration, softening point, and then on Marshall properties.

- The using of WTR in the present study in a specified amount had been approved, that it is very effective and useful to enhance the properties of asphalt cement. Where there is, no previous research studied could classify the types of waste rubber to WCR and WTR to know the affecting of using that as the present study done.

- The elevation on all independent variables to limited ranges will be more useful in condition of stopping this elevation on the maximum ranges in this study (i.e. optimum values) and equal or more than the critical limits.

- Mathematical models had been found to be more useful in predicting the required responses where the using of STATISTICA software had increase the accuracy of estimating the parameters, critical and optimum values.

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Glossary

Symbol	Description	Unit
AASHTO	American Association of State Highway and Transportation Officials	-
ASTM	American Society for Testing and Materials	-
AC	Asphalt Cement	gm
AR	Asphalt Rubber	Ton
F_{m1}	Constant factor for the instrument Marshall stability	-
CRM	Crumb Rubber Modifier	gm
HMA	Hot Mix Asphalt	Ton
MAC	Modified Asphalt Cement	gm
Y_{Real}	Penetration response real value	mm
VFA (%)	Percentage of voids filled with asphalt cement	-
VMA(%)	Percentage of voids in the mineral aggregate	-
VTM (%)	Percentage of voids in the total mix (air voids)	-
G_{Real}	Softening response real value	℃
S.O.R.B.	State Organization of Roads and Bridges/Iraq	-
WCR	Waste Car tire Rubber	gm
WTR	Waste Truck tire Rubber	gm