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Deterministic Extensional Viscosity and Cracking Index of Polypropylene-Modified-Asphalt Binder

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A B S T R A C T

The extensional viscosity and cracking prospectus of polypropylene modified asphalt cement (PPMAC) was explored. Forty/fifty penetration class asphalt cement with five-contents of polypropylene polymer were chosen. Conventional traits such as: Standard penetration, standard softening point, ductility, utter viscosity, elasticity moduli, penetration prospectus, ageing, cracking prospectus, homogeneity, and extensional viscosity were performed on PPMAC. The PPMAC shows better viscosity, elasticity, enduringness and lower cracking properties at cold regions.

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حساب اللزوجة ودليل التشققات للإسفلت المطور بالبولي بروبلين

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الخلاصة

تتضمن الدراسة إيجاد اللزوجة ودليل التشققات للإسفلت المحسن بالبولي بروبلين polypropylene modified-asphalt binder (PPMAC) اعتمادا على خصائص الإسفلت والركام. أختير الإسفلت ذو النفاذية (40\50) وأربعة تراكيز للبولي بروبلين، أجريت فحوصات الاختراق، الاستطالة، معامل المرونة، اللزوجة المطلقة، تأثير الحرارة، معامل التشققات، والتجانس. اظهرت النتائج تحسن أداء الإسفلت المطور بمادة البولي بروبلين من حيث امتلاكه لقيم لزوجة عالية ومقاومته لتأثير درجات الحرارة مقارنة بالإسفلت غير المطور.

الكلمات الدالة: البولي بروبلين، التقادم، معامل التشققات، اللزوجة المطلقة.

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SYMBOLS

AP: Aging prospectus
CP: Cracking prospectus
E_b: Stiffness modulus of asphalt (N/Sq.mm)
EV: Extensional viscosity
L: Loading period (secs.)
PE: Polyethylene
PI: Penetration index
PP: Polypropylene
PPR: Penetration prospectus
S.P: Aged softening temperature in (deg. C)
SD_{25}: Standard ductility
SP_{25}: Standard penetration
T_{asp}: Temperature of the asphalt concrete layer
T_b: Pavement temp. (deg. C)
$T_{R\&B}$: Recovered asphalt softening temperature
TT: Temp. of test
UV: Utter viscosity
V_b: Asphalt EV (N/Sq.mm.s.)

1. INTRODUCTION

Non-load-concerned cracking of asphalt concrete pavements at low-temperature is prevalent worldwide at Iraqi northern region. This distress introduces transverse cracks, spalling, etc. and in turn reduced service life of the pavement. Thus, physical traits evaluation of asphalt is primary.

On the other hand, polymers/asphalt mixes within expand domain of contents and kinds perform good implementation in the design of flexible concrete pavements [1-19]

Polyethylene (PE) and polypropylene (PP) are worldwide used polymers in paving applications. Thus, PP was used in this research due to its lower price and added content.

However, this study tries to calculate the (1) standard penetration (SP_{25}), standard ductility (SD_{25}), softening temperature (TR&B), utter viscosity (UV), elasticity modulus (E_b), penetration prospectus (PPR), aging (enduringness), cracking prospectus (CP), compatibility, to distinguish the gained tests data with virgin binder, and extensional viscosity traits of PP/asphalt cement (PP/AC); and (2) distinguish the gained tests data with neat mixes, and extensional viscosity of PP/ asphalt mix (PPMAM).

2. CONTENT OF THE PRESENT RESEARCH

Standard assays (SP25, SD25, TR&B, UV, Eb, percent loss in heat, aging prospectus (AP), CP, compatibility, PP and extensional viscosity) of PPMAC, as well as, extensional viscosity of PPMAM were performed in this research.

The PP in pellet shape with five contents was used as an additive for AC-50 Iraqi bitumen.

3. MATERIALS AND TESTS PROCEDURES

3.1. AC50

AC50 was utilized to make PPMAC. Table 1 depicts AC traits.

Table 1
Basic AC properties.

Property	Result	ASTM [10]
Std. Pen., 0.1mm	42	40-50
R&B, °C	54	50-58
Ductility	150^{+}	>100
Sp. gr	1.053	1.01-1.06
Flash point	263	>240
% Loss on heat	0.25	0.2 max
Asphaltenes	32.65	-

3.2. PP-modifier

The PP with 0.6 g/cc average density and 158.5161± 2.5 °C melting point was blended with AC-50. Five PP-contents were introduced into AC-50 for 2 hrs at 170±5ºc using 3000 rpm mixer to produce homogeneity binder [20].

4. RESULTS AND DEBATY

4.1. SP25, SD2 and TR7B

The PPMAC traits (i.e. SP_{25}, SD_{25}, and $T_{R\&B}$) test results are tabulated in Table 2. Analysis of laboratory results notice that the values of SP_{25}, SD_{25} and $T_{R\&B}$ were significantly enhanced with PP-addition. 3%PPMAC reveal 25% lower P_{25}, 9.3% higher $T_{R\&B}$ data than AC50. This explores that PP varies AC50 behavior.

Analyzing Table 2 explores that 3%PPMAC satisfied the minimum ranges of SCRB [21] and ASTM [22] of 100^{+} cm D_{25}.

Table 2
Traits of PP-AC50.

% PP	SP_{25}	SD_{25}	$T_{R\&B}$ (°C)	UV, 21°C, poise (million)
0.0	42.0	>150	54.0	5.0
1.0	39.0	133	55.5	5.78
3.0	31.5	115	59	9.2
6.0	23.7	82	66	17
9.0	21.5	74	75	21

4.2. Utter Viscosity (UV)

The PP/AC50 binder utter viscosity at 21°C was calculated from shell chart. Table 3 depicts the UV with PP-dosages. Analysis of the laboratory test results noticed that 3%PPMAC showed 84% higher AV than AC-50.

Table 3
TFOT Characteristics of PP/AC50 Binders.

PP, dosage	Residue SP_{25}	AP	Residue SD_{25}	$T_{R\&B}$ °C	Loss in heat, %
0.0	37.0	0.880	142.0	56.0	0.250
1.0	35.0	0.897	126.75	58.0	0.210
3.0	29.5	0.936	74.0	61.0	0.150
6.0	21.1	0.89	47.5	68.5	0.121
9.0	17.5	0.813	45.5	82.0	0.105

4.3. Elastic (stiffness) Modulus

The elastic (stiffness) modulus of PP/AC50 binder was determined utilizing Van der poel Eq. (1) as reported by [23], [24].

$$E_b = 1.157 * 10^{-7} * \tau^{-0.368} * 2.178^{-PI.} (T_{R\&B} - T_{asp.})^5 \quad \text{---------} (1)$$

If:

E_b=Stiffness modulus of asphalt (N/Sq.mm),

$T_{R\&B}$ = $T_{R\&B}$ after asphalt recovery (°C),

T_{asp} = Temperature of the asphalt concrete layer, °C

PI. = Pen. index of asphalt after recovery and

L=Loading period (secs.).

Eq. (1) is only appropriate when:

1/100 sec <τ< 1/10 sec,

-1.0 <P.I. < 1.0,

20 deg.C < ($T_{R\&B}$ - T_{asp})< 60 deg.C.

Fig. 1 explores that 3%PPMAC notice 50.2% extra E_b than AC50.

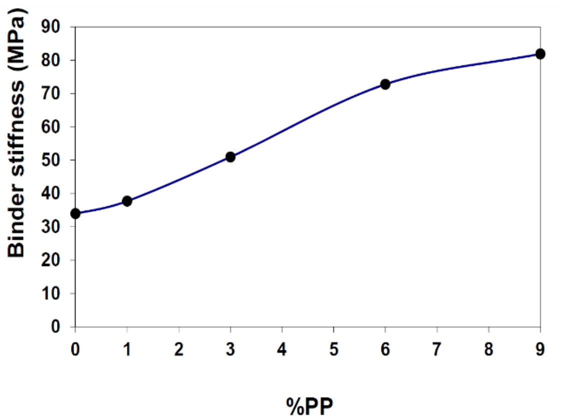

Fig. 1 Binder stiffness of PPMAC

4.4. Penetration Index (PI.)

PI of PPMAC was determined by PI. [Eq. (2)] reported by [25]:
PI. = [(20-500Z)/ (1+50Z)] --------- (2)
Z = [(logarithm pent.@TT-logarithim 800)/ (TT-$T_{R\&B}$)]
Where:
TT = Temp. of test.
T_{R2B}= Softening temp., °C
The PI comparison test data, as depicted in Figure. 2, notices that the preliminary and recovered PI. data for all PPMAC fall between -0.5 and -1.0 as reported in KSLA monograph [25].

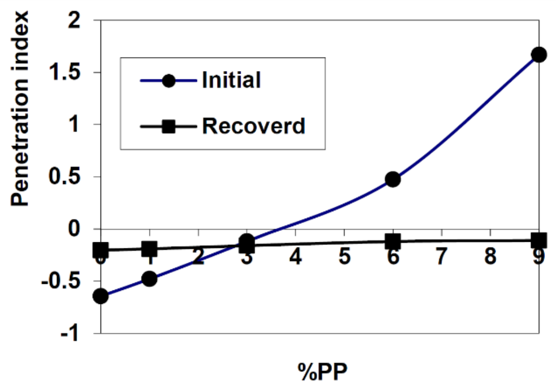

Fig. 2 Penetration index of PPMAC

4.5. Compatibility Test

The compatibility of PPMAC was executed by passing PPMAC through 0.15 mm sieve opening at 165 deg. C. The results depict that PPMAC can be saved for next use [10].

4.6. Aging Traits

SP_{25}, SD_{25} and $T_{R\&B}$ behind thin film oven test (TFOT) were explored. Aging prospectus (AP) = ($SP_{25,}$ residue / SP_{25}) calculated as reference for hardening. Table 3 tabulates AP., residue ductility and softening point after ageing values of PP/AC50 specimens. It can be noticed that PPMAC has higher AP than AC50 (improved short-term aging characteristics). Analyzing, Table 3 showed that 4%PPMAC reached the minimum SCRB required limits of 100^+ cm aged SD_{25}. In addition, it was found that 3% PP dosage increased durability of AC-50 by 40%.

4.7. Cracking Trait at Lower Temperatures

Flexible pavements thermal cracking is noticeable and higher cost pavement failure mode is noticed in several sites of higher cool environments. The reason mainly concerns low temperatures occurrences, which produce paving materials tensile stresses as a results fracture occurred [26].

A lot of procedures of evaluating the distress intensive of transverse cracks have been reported by researches. One of the commonly utilized approaches is the cracking prospectus (CP) concept [27]. (Al-Ani, 1999) explores a good relation (r = 0.918) for estimating cracking at low temperatures depending on asphalts traits before and after TFOT. The CP is illustrated in Eq. (3):
CP = 10.0330 (AP) $^{1/2}$ – 166.204 + 0.334 logarithm (SP_{25}) + 3.3148 (S.P.) .... (3)
Where:
CP = Cracking prospectus,
AP = Aging prospectus,
SP_{25}= Std. penetration,
S.P. = Aged softening temperature in deg. C.
The CP comparison test results, as depicted in Fig. 3, show that the CP for AC50 and 3%PP/AC50 are 20.0 and 36.0, respectively. 3% PP raises CP by 80%. This shows that PP/AC50 enhances asphalt mixes resistance against cracking because PP/AC50 has low temperatures damage.

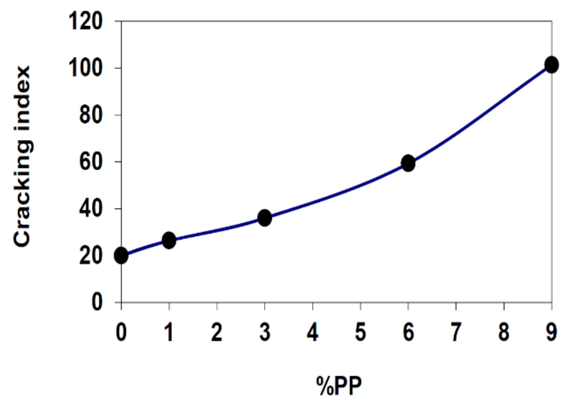

Fig. 3 Cracking prospectus of PPMAC

4.8. Extensional Viscosity (EV)

EV of PP/AC-50 and mix are reported in Equations 4 & 5 [28].

$\lambda_b = 3 * 10^{-6} \{ 1.3 * 10^{[3 + (TR\&B - Tasp.)/10]} \}$ --------- (4)

Where:

V_b = Asphalt EV (N/sq.mm.s.),

$T_{R\&B}$ = Recovered asphalt softening temperature (deg. C), and

T_b = Pavement temp. (deg. C).

Logarithm $(V_a) = A_1(Y) + A_2(Y)$ logarithm (V_b) ----- (5)

$A_1(Y) = 186\times10^{-5} * Y^2 + 6.98 - 165\times10^{-3} * Y$

$A_2(Y) = 0.75 - 22\times10^{-5} * Y$

Where:

V_a = Mix EV (N/sq.mm.s.), and

Y = Voids in aggregates, %.

Figure 4 & 5 notices that 3% PP raises the EV of AC50 and virgin mix at 60 °C by 118.2% and 34.9%, respectively. Further, increase in temperature causes reduction in binder and mix EV for 0% and 3% PP dosages as depicted in Fig. 6 and Fig. 7.

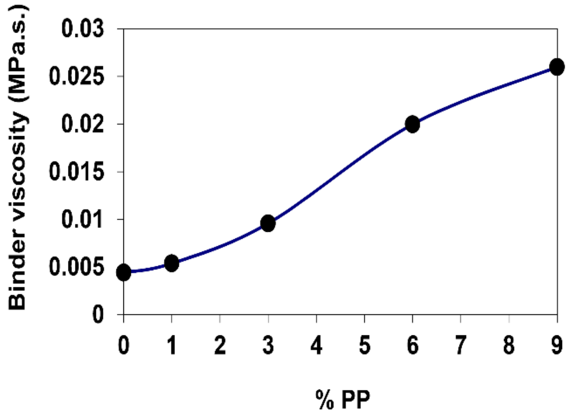

Fig. 4 EV of PPMAC (60 °C)

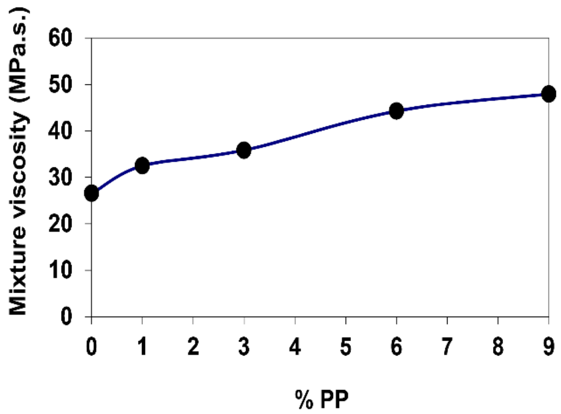

Fig. 5 EV of PPMAM (60°C)

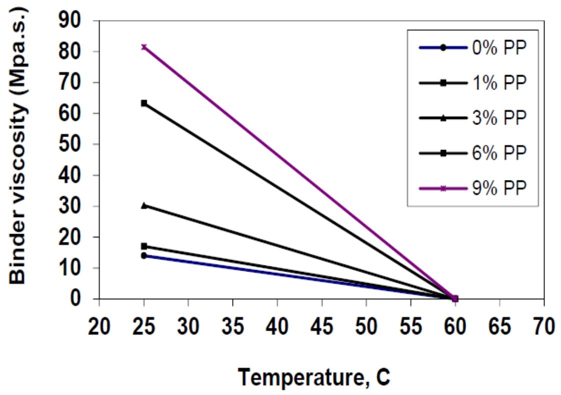

Fig.6 EV of PPMAC (25 and 60 °C) temperatures

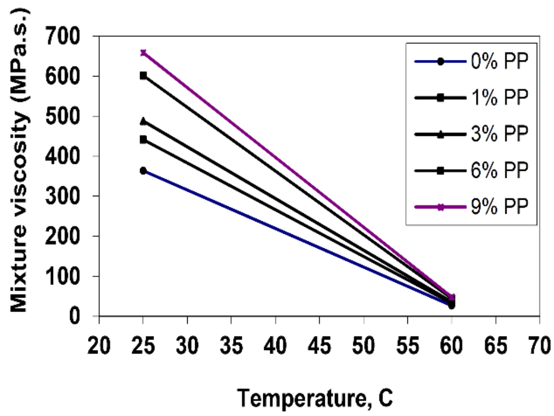

Fig.7 EV of PPMAM (25 and 60°C) temperatures

5. CONCLUSIONS

The study reached at the following findings:

1. SD_{25} will commonly reduce as PP rate rises, which notices enhanced resistance against shear in moderate to high temperature.
2. 3%PPMAC reached the minimum SCRB and ASTM required standards of 100^+ cm SD_{25}.
3. 3%PPMACshows 9.3% higher than AC50 $T_{R\&B}$. This notices enhancement against deformation.
4. Preliminary and recovered PI values depicted that PP minimized the temperature damage of asphalt.
5. 3% PP rate shows 84% higher UV, 50.2% higher elastic modulus, and 40% higher durability than AC50.
6. The compatibility test indicated that PP and asphalt are compatible to an extent.
7. It was found that the AP increases with increment in PP rate (i.e. improved short-term aging characteristics).
8. 3% PP raises the CP by 79.8%. This shows that the PPMAC enhances asphalt mixes cracking resistance; and
9. 3% PP rate raises EV of AC50 and its mix at 60°C by 118.2% and 34.9%, respectively.

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