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Durability of Asphalt Mixture in Different Corrosion Solution

CHEN Shuanfa[1,2], GUAN Bowen[1,2*], XIONG Rui[1], SHENG Yanping[2], HE Rui[1]
(1. Key Laboratory for Special Area Highway Engineering of Ministry of Education, Chang' an University, Xi' an 710064, China; 2. School of Materials Science and Engineering, Chang'an University, Xi'an 710061, China)

Abstract: The corrosion to asphalt mixture under different kinds of corrosion solution, such as pH=2 solution, pH=12 solution, pH = 12 solution and 10% Na_2SO_4 solution, was studied. The performance attenuation of asphalt mixture was analyzed under the normal environment and the freeze-thaw environment, and the analysis was given on the sensitivity of the test results to the evaluation index. The experimental results show that the performance of asphalt mixture is attenuated faster under the acidic solution, alkaline solution and sulfate solution. Corrosion factor K_c, freeze-thaw corrosion factor K_f, and freeze-thaw effect factor K_{fc} are proposed to evaluate asphalt mixture resistance to corrosion in different kinds of corrosion solution. The values of K_c and K_{fc} decrease with the increasing of corrosion time. The change rule of K_f show that the rate of corrosion is decreased by the action of freeze-thaw in acidic solution and in alkaline solution, but is increased by the action of freeze-thaw in sulfate solution. The microscopic analysis indicates that acid solution reacts with aggregate of asphalt mixture, alkaline solution reacts with asphalt cement of asphalt mixture, the surface tension of sulfate solution and crystallization of sulfate are the main reasons which weak the performance of asphalt mixture.

Key words: asphalt mixture; corrosion damage; corrosion mechanism; corrosion evaluation

1 Introduction

Moisture damage is one of the main forms of distresses in the asphalt pavement[1-3]. Presently, a lot of research has been done on the mechanism of moisture damage in the asphalt pavement at home and abroad, but most of work was focused on the physical interaction between water and asphalt mixture, such as the strength of asphalt mixture is softened by water, asphalt binder is peeled off easily from the aggregate surface due to water immersion, scouring and pumping effect of dynamic water caused by repeated vehicle load, *etc*[4-7]. However, asphalt mixture can be easily corroded under harsh environment such as acidic, alkaline and sulfate corrosion solution. The harsh environment areas in china are shown in Table 1. Since AC dense-graded mixture is widely used for asphalt pavement in China, the evaluation system and mechanism of corrosion of AC asphalt mixture were studied.

Table 1 Areal distribution of different corrosion types

Type	Distribution
Acid rain	Central, southwest, east and south china, account for 30% of land area
Alkaline	RainInner mongolia, gansu, qinghai, xinjiang and other arid and semi- arid areas, coastal areas, *etc*
Sulfate	Coastal areas, western salt lake area, *etc*

2 Experimental

2.1 Raw materials

SBS modified asphalt was used. Table 2 shows the test results of asphalt (JTJ052-2000, 2000).

The coarse, fine aggregate and mineral powders are belong to limestone. Each technical indicator is accordance with specification requirements (JTJ052-2000, 2000).

AC-13 dense gradation for asphalt mixture is adopted, which is shown in Table 3.

2.2 Test methods

The distilled water and three kinds of corrosion solution were prepared based on the value of pH, shown in Table 4. Two kinds of test condition, normal condition and freeze-thaw cycle condition were considered to test the influence of corrosion solution on the moisture damage of asphalt mixture, shown in Table 5[8].

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CHEN Shuanfa(陈拴发)：Prof.; Ph D; E-mail: chenshuanfa@sohu.com
*Corresponding author: GUAN Bowen(关博文) : Ph D Candidate; E-mail: guanbowen2001@163.com
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Table 2 Test Results of SBS modified asphalt

Test Items	Penetration (100g, 5s, 25℃) /0.1mm	Ductility(5℃) /cm	Softening point/℃	Residue after RTFOT		
				Mass loss	Penetration ratio of 25 ℃/%	Ductility(5℃) /cm
SBS	71	48	89.5	−0.02	68.9	24

Table 3 AC−13 gradation of aggregate

Diameter of seive mesh/mm	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing ratio in mass/%	100	95.5	68	47.1	33.4	23.4	15.2	8.7	7.3	5.2

Table 4 Solution preparation table

Type	pH	Ingredients
Normal solution	pH=7	Distilled water
Acid solution	pH=2	H_2SO_4 and HNO_3 (molar ratio 9:1) in distilled water
Alkaline solution	pH=12	NaOH in distilled water
Sulfate solution	10% Na_2SO_4	10% Na_2SO_4 in distilled water quality

Table 5 Experimental condition table

Condition	Corrosion time	Temperature
Norma	l40 h and 120 h	60 ℃
Freeze-thaw cycle	1 and 3 freeze-thaw cycles,1 freeze-thaw cycle was 40 h	16 h at −18 ℃ and 24 h at 60 ℃

3 Results and Discussion

3.1 Experimental results

Splitting strength experimental Results are shown in Fig. 1 and Fig. 2.

It can be clearly seen from Figs.1 and 2 that the attenuation of splitting strength of asphalt mixture under the solutions with pH = 2, pH = 12 and 10% Na_2SO_4 are larger than that under the solution with pH=7. At the same time, the attenuation of splitting strength of specimen immersed in 10% Na_2SO_4 solution, which is decreased by 7.9% for 40 h and 18.6% for 120 h, is smaller than that of specimen immersed in the solution with pH=2, which is decreased by 13.6% for 40 h and 26.4% for 120 h. On the contrary, after 3 freeze-thaw cycles, the attenuation of splitting strength of specimen in 10% Na_2SO_4 solution is up to 69.3%, much more than in pH=2 solution. It indicates that the action of freeze-thaw cycles have great influence on the physical and chemical interaction between corrosion solution and asphalt mixture.

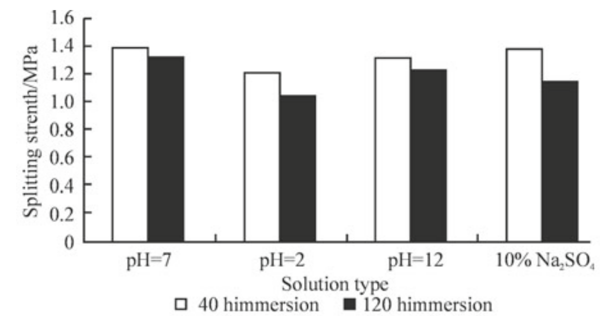


Fig.1 Splitting strength with 4 kinds of different solution under normal condition

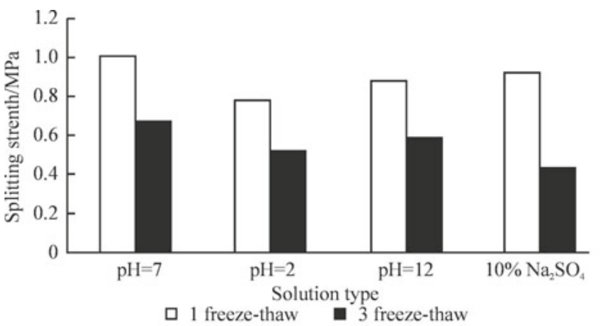


Fig.2 Splitting strength with 4 kinds of different solution under freeze-thaw condition

3.2 Evaluation index

Little research has been done on the asphalt mixture corrosion damage in harsh environment at home and abroad. So there is no corresponding evaluation method and index of corrosion. Corrosion factor, freeze-thaw corrosion factor and freeze-thaw effect factor were proposed to evaluate asphalt mixture resistance to corrosion in different kinds of corrosion solution in the paper. And the effect of freeze-thaw action to the corrosion damage was studied too.

3.2.1 Corrosion factor

Corrosion factor K_c reflects the relative performance changes of asphalt mixture in solution corrosion under normal environment(equation 1). Equation (1) shows that that larger the value of K_c is, better the corrosion resistance of asphalt mixture is.

$$K_c = f_c / f_w \tag{1}$$

where, f_c—splitting strength after soaking in the corrosion solution,MPa; f_w—splitting strength after soaking in the distilled water, MPa.

3.2.2 Freeze-thaw corrosion factor

Freeze-thaw corrosion factor K_{fc} reflects the relative performance changes of asphalt mixture in solution corrosion under the freeze-thaw environment(Equation 2). Equation (2) shows that larger K_{fc} is, better the freeze-thaw erosion resistance of asphalt mixture is.

$$K_{fc} = f_{fc} / f_{fw} \tag{2}$$

where: f_{fc}—splitting strength after freeze-thaw erosion,MPa; f_{fw}—splitting strength after freeze-thaw in distilled water, MPa.

3.2.3 Freeze-thaw effect Factor

Freeze-thaw effect factor K_f reflects the action of freeze-thaw cycles on the corrosion of the solution(equation 3), which is the ratio of the strength corrosion loss ratio in the freeze-thaw condition and normal condition.

$$K_f = \frac{\dfrac{f_{fw} - f_{fc}}{f_s}}{\dfrac{f_w - f_c}{f_s}} = \frac{f_{fw} - f_{fc}}{f_w - f_c} \tag{3}$$

where, f_s—splitting strength of standard specimen, MPa.

In the equation (3), when the value of $K_f > 1$, the action of freeze-thaw cycle accelerate the solution of corrosion; when the value of $K_f = 1$, the action of freeze-thaw cycles have no effect on the corrosion solution; when the value of $K_f < 1$, the action of freeze-thaw cycles slow down the solution of corrosion.

3.3 Evaluation of corrosion resistance

The value of K_c, K_{fc} and K_f of the asphalt mixture in normal condition and freeze-thaw condition are listed in Table 6. From the Table 6, it can be seen that the values of K_c and K_{fc} are less than 1 in acid solution, alkaline solution and sulfate solution. It indicates that corrosion solution reacts with asphalt mixture and attenuates the performance of asphalt mixture. K_f in acid solution and alkaline solution has different influent law from in sulfate solution, which indicates that the action of freeze-thaw cycles have great influence on the physical and chemical interaction between corrosion solution and asphalt mixture in different solutions. Since the corrosion mechanism with different solutions is different, the corrosion behavior and mechanism of asphalt mixture under different kinds of solution was discussed respectively.

3.3.1 Acid solution

Influence of acid solution corrosion time on K_c, K_{fc} and K_f are shown in Figs.3-5. From Fig. 3, it can be seen that the value of K_c decreases with the increasing of corrosion time. The reason is that the corrosion action of acidic solution on mineral aggregate leads to form a lot of pores and defects, which were showed in Fig.6. The further penetration of acidic solution will accelerate the chemical reaction between acid and mineral aggregate. The pores and defects lead to higher specific surface area of asphalt exposed in acidic solution, and cause the stripping of asphalt[9].

From Fig. 4 and 5, it can be seen that the value of K_{fc} decreases with the increasing of freeze-thaw time and the value of K_f increases firstly and then

Table 6 Corrosion resistance evaluation

Solution	40 h immersion/ 1 freeze-thaw cycle			120 h immersion/ 3 freeze-thaw cycles		
	K_c	K_{fc}	K_f	K_c	K_{fc}	K_f
pH=2	0.871	0.782	1.222	0.780	0.776	0.517
pH=12	0.950	0.861	2.000	0.924	0.881	0.800
10% $NaSO_4$	0.928	0.911	0.900	0.863	0.642	1.333

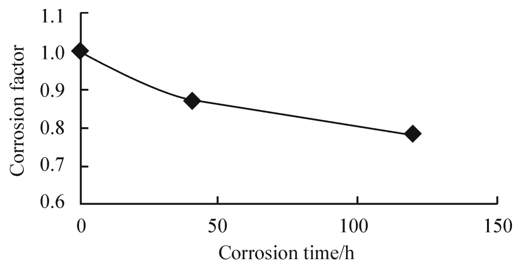


Fig.3 Corrosion time influence on K_c

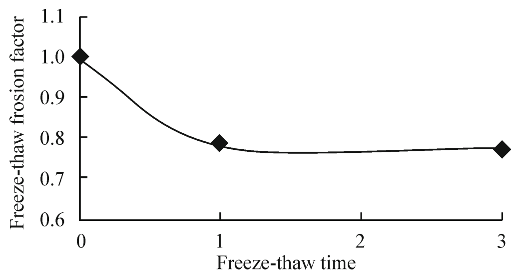


Fig.4 Corrosion time influence on K_{fc}

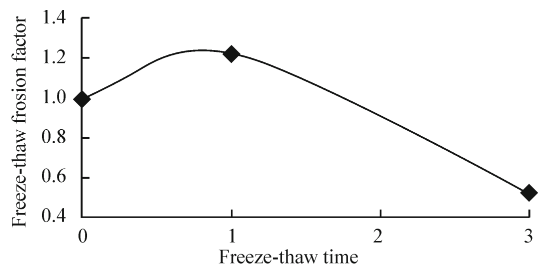
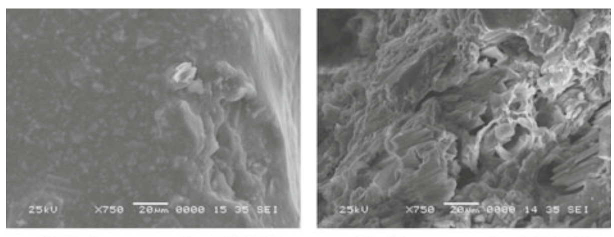


Fig.5 Corrosion time influence on K_f



(a) Before corrosion (×750) (b) After corrosion (×750)

Fig.6 SEM images of asphalt mixture in acid solution decreases rapidly with the increasing of freeze-thaw time. The reason is that under the action of freeze-thaw cycles, surface course mineral aggregate and aggregate uncoated by asphalt cement in the asphalt mixture will be broken up, which will accelerate the chemical reaction between acid solution and mineral aggregate of asphalt mixture. But with the increasing of reaction time, the reaction between exposed mineral aggregate and corrosive solution finishes and the reaction in low temperature stages during the freeze-thaw cycles becomes weak.

3.3.2 Alkaline solution

Alkaline solution corrosion time influence on K_c, K_{fc} and K_f are shown in Figs.7-9. Fig.7 shows that the value of K_c decreases with the increasing of corrosion time. Because of the asphalt in asphalt mixture reacts with alkaline solution, which is showed in some relevant literature, the asphalt film covering mineral aggregate become thinner, and water will infiltrate the interface between asphalt and aggregate, then the bonding capacity of asphalt and aggregate will be reduced gradually[10]. In the test, a large number of suspended particles which are pro- exist on soaking solution and asphalt surface, which is shown in Figs.8-10, show that the value of K_{fc} decay rapidly and then increases slightly and the value of K_f first increases and then decreases with the increasing of freeze-thaw time. During the freeze-thaw cycles, a large number of micro-cracks will be produced at the asphalt mixture surface, which increases the contact area between asphalt surfaces and promotes the reaction. After a period reaction time, a large number of suspensions generated attaching to asphalt mixture surface and micro-cracks during the early reaction stage, which will prevent further reaction. At the same time, low temperature stages during the freeze-thaw cycles alleviate the reaction between asphalt and alkaline solution to some extent.

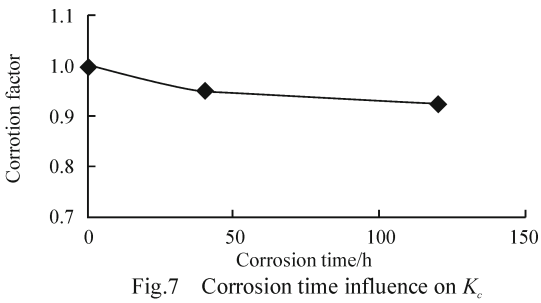


Fig.7 Corrosion time influence on K_c

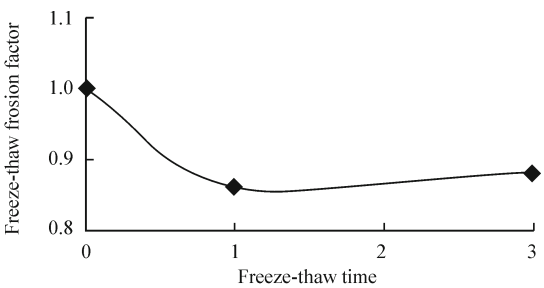


Fig.8 Corrosion time influence on K_{fc}

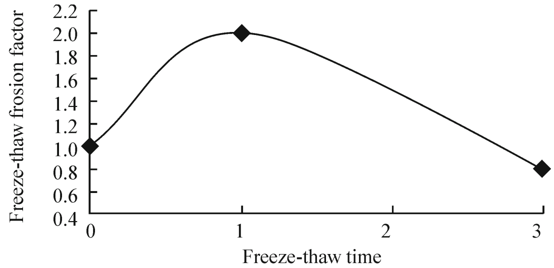
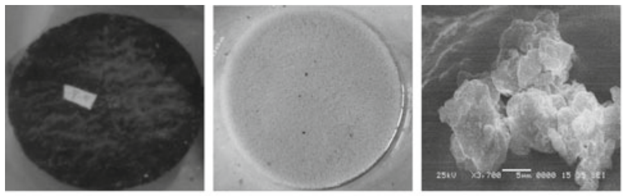


Fig.9 Corrosion time influence on K_f



(a) Reaction products on the asphalt mixture (b) Micro-morphology of reaction products (c) Collection of reaction products

Fig.10 Asphalt attachment and micro-morphology of asphalt attachment

3.3.3 Sulfate solution

Sulfate solution corrosion time influence on K_c, K_{fc} and K_f are shown in Figs.11-13. Fig. 11 shows that the value of K_c decreases with the increasing of corrosion time. Because of the surface tension of 10% Na_2SO_4 solution is larger than that of distilled water, the permeability of asphalt mixture and the saturation of the surface layer are enhanced, and moisture damage of asphalt mixture will be accelerated.

Fig.12 shows that the value of K_{fc} decreases with the increasing of freeze-thaw time. Fig. 14 indicates that plenty of cracks and sulfate crystals will be produced in the inner of asphalt mixture after the action of freeze-thaw and corrosion. It can be inferred that

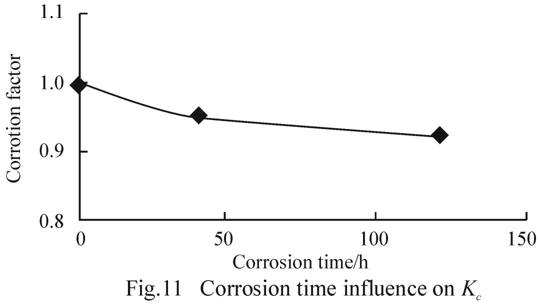


Fig.11 Corrosion time influence on K_c

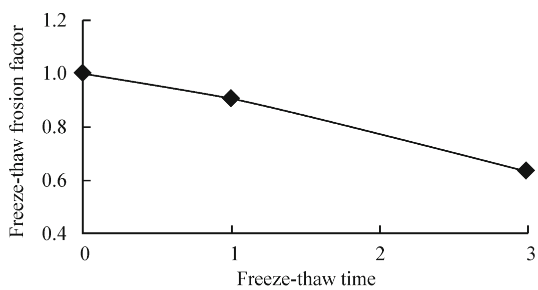


Fig.12 Corrosion time influence on K_{fc}

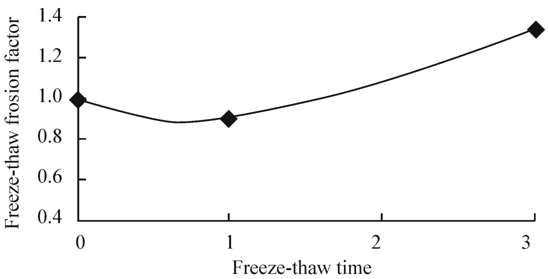


Fig.13 Corrosion time influence on K_f

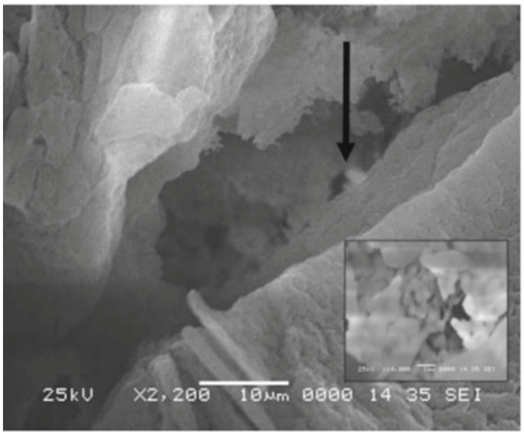


Fig.14 Na_2SO_4 crystals in the ice expansion crack

volume expansion after solution gets iced up produce many cracks in the asphalt mixture and Na_2SO_4 solution will penetrate into the cracks and form the erosion of crystalline fracture, because of low temperature. Not enough micro-cracks exist before the first freeze-thaw cycle. Corrosion damage will be accelerated when a lot of sulfate solution enters into the existing cracks, so the valued of K_f first decrease slightly and then increased rapidly with the increasing of freeze-thaw time, which is shown in Fig. 13.

4 Conclusions

The corrosion damage of asphalt mixture, the evaluation system and mechanism of corrosion of asphalt mixture in pH=2 solution, pH=12 solution and 10% Na_2SO_4 solution was studied. Some conclusions are obtained as follows:

a) The performance of Asphalt mixture will be attenuated faster in pH=2 solution(acid solution), pH=12 solution (alkaline solution) and 10% Na_2SO_4 solution(sulfate solution) than in pH=7 solution(distilled water).

b) Corrosion factor K_c, freeze-thaw corrosion factor K_f and freeze-thaw effect factor K_{fc} are proposed to evaluate corrosion damage of asphalt mixture, which can accurately reflect the corrosion resistance of asphalt mixture.

c) Freeze-thaw circulation on the corrosion of different kinds of solution has different effects. The action of freeze-thaw circulation decays corrosion in acid and alkali solutions, but facilitates corrosion in sulfate corrosion.

d) Based on the test study and analysis of microscopic image, it can be concluded that acid solution reacts with aggregate of asphalt mixture, alkaline solution reacts with asphalt cement of asphalt mixture, the surface tension of sulfate solution and crystallization of sulfate are the main reasons which weak the performance of asphalt mixture.

References

[1] Gorkem, Cagri , Sengoz, Burak. Predicting Stripping and Moisture Induced Damage of Asphalt Concrete Prepared with Polymer Modified Bitumen and Hydrated Lime [J]. *Construction and Building Materials*, 2009, 23(6): 2 227-2 236

[2] Xiao Feipeng, Amirkhanian, Serji N. Laboratory Investigation of Moisture Damage in Rubberised Asphalt Mmixtures Containing Reclaimed Asphalt Pavement[J]. *International Journal of Pavement Engineering,* 2009 ,10(5): 319-328

[3] Yang Ruochong, Liang Xisan, Lai Yongman. Typical Causes and Countermeasures of Moisture Damage for Asphalt Pavement [J]. *Journal of Tongji University (Natural Science),* 2008, 6:749-753

[4] Kim, Yong-Rak, Little, Dallas N, Lytton Robert L. Effect of Moisture Damage on Material Properties and Fatigue Resistance of Asphalt Mixtures[C]. In: 83*rd Annual Meeting of the Transportaion-Research-Board*, Washington DC, 2004, 1891: 48-54

[5] Cho Dong-Woo, Bahia Hussain U. New Parameter to Evaluate Moisture Damage of Asphalt-aggregate Bond in Using Dynamic Shear Rheometer [J]. *Journal of Materials in Civil Engineering,* 2010, 22(3)267-276

[6] Birgisson, Bjorn, Roque, Reynaldo, Page, Gale C. Evaluation of Water Damage Using Hot Mix Asphalt Fracture Mechanics [C]. In: *Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions,* 2003, 72:424-462

[7] Cheng DingXin, Little Dallas N, Lytton Robert L. Moisture Damage Evaluation of Asphalt Mixtures by Considering Both Moisture Diffusion and Repeated-Load Conditions[C] In: *82rd Annual Meeting of the Transportaion-Research-Board*, Washington DC, 2003, 1832: 42-49

[8] Wu Shaopeng, Ye Qunshan, Li Ning. Effects of Fibers on the Dynamic Properties of Asphalt Mixtures[J]. *Journal Wuhan University of Technology-Materials Science Edition*, 2007, 22(4):733-736

[9] James W, Shahin R. A Laboratory Examination of Pollutants Leached from four Different Pavements by Acid Rain [C]. In: *Conference on Stormwater and Water Quality Management Modeling,* Toronto Canada, 1997, 6(6):321-349

[10] GUO Jixiang, Liu Qing, Li Mingyuan. The Effect of Alkali on Crude Oil/Water Interfacial Properties and the Stability of Crude Oil Emulsions [J]. *Colloids and Surfaces,* 2006, 273:213-218