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UCT Journal of Research in Science, Engineering and Technology

UCT. J. Resea. Scien. Engineer. Techno. (UJRSET)

Volume 4 ,Issue 4

22-30 (2016)

ISSN 2382-977X

Analysis Fracture Behavior of Asphalt Mixtures in Freezing and Thawing Cycles Conditions Using Linear Elastic Fracture Mechanic (LEFM) Technic

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Original Article:
Received 10 Sep. 2016 Accepted 18 Oct. 2016 Published 28 Nov. 2016

ABSTRACT

Today, cracking asphalt pavement in low temperature is one of the obstacles for protecting pavement in the cold climates. One of important factors in extending of these types of cracking is cooling and heating temperature cycles according to the changes in seasons. Therefore, this research examines these types of asphalt cracking by considering asphalt mixtures and using mechanics science. In this research, cold environmental conditions were determined by making asphalt gyratory asphalt samples and fracture test in -15°C to study the effect of asphalt mixtures important parameters, it means asphalt construction materials textile on fracture resistance of samples. On the other hand, simultaneous effect of two parameters on asphalt fracture resistance was examined by considering the effect of freezing and thawing cycles, as well as using siliceous and calcareous materials.

Keyword:
asphalt mixtures, freezing and thawing cycles, linear elastic fracture (LEF)

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Peer review under responsibility of **UCT Journal of Research in Science, Engineering and Technology**

INTRODUCTION

Fracture mechanics is one of important issues in mechanical engineering, which studies the fracture process, its prediction, and control in the cracked materials. In this branch of mechanical engineering used extensively today in various engineering fields, germination, and growth of cracks, fracture criteria, and strength, fatigue, and creep phenomena in cracked materials must be examined. Since fracture occurs in many engineering segments and causes their final fracture, it is essential to study fracture mechanical issues to find fracture behavior and properties of cracked samples, and fracture criterions of materials more than ever. Researchers found out in studying the reasons of fracture that designing many structures based on the common methods have been proper; however, it was concluded after research that the main factor of fracture were defects and very tiny fractures in structure or which were made while working with them [1]. According to the energy conception, fracture occurs when the needed energy to grow crack or fracture is enough to cope with the resistances among the present elements. Griffiths used this concept for the first time to examine the fracture behavior of brittle materials.

Materials are usually divided to brittle & ductile classes according to fracture properties. The brittle materials mainly make quick growth of fractures in materials under stress. According to definition, toughness indicates a material ability against plastic deformation and the absorbed energy before and while fracture. In other words, plastic deformation and the absorbed energy before fracture are low for brittle materials and high for ductile materials. This fracture is the worthiest type, because no significant destruction can be seen in structure before fracture. Fractures are usually vertical on the inserted stress in ductile fractures. Although, fracture mechanics has developed in recent decades, one of its equation was institutionalized by Griffith in 1921. According to Griffith [3] efficient energy potential must be in access to cope with surface energy to increase fracture size.

LEFM theory can states the fracture level approximately if plastic area is smaller than the fracture size. LEFM technology is related to the magnitude of stress and distribution around fracture peal to the partial inserted stress to the structural element. Stress intensity factor (SIF), K_1, will lose its meaning when plastic area is more extended, the critical SIF, K_{1C}, was designed for unstable fracture for mode (I) change and small plastic mode changes. K_{1C} is the instinct ability of materials to resist against the inserted stress intensities in fracture peak and resistance against the extension of tensile stress. (37)

Effective factors on fracture progress include stress magnitude, deformation, and fractures sizes in materials that control stress focus in the fracture peak. Start prediction criterion and fracture in the asphalt pavement body is stress intensity factor (K) that stress intensity near sharp fracture peaks show linear elasticity of a material. According to various fracture forms, critical stress intensity factor can be defined for all of these formations. If the SIF in a point of pavement or near fracture exceeds the mentioned values, fracture will progress.

Fractures are the most significant failures on pavements that are an inconsistency on pavement with minimum width of 1mm and minimum length of 25mm according to AASHTO regulations [11]. Fracture occurs by various factors such as traffic load, temperature changes, and underlying subsidence. The fracture reason is principally temperature changes and traffic load extend and develop fractures more. In high temperatures, the main model of fracture in asphalt concrete is rutting, but fracture usually occurs in asphalt pavements in low temperature, and this makes asphalt to fracture without so many changes in appearance. Yet, friction between asphalt and the base layer resists against contraction. If the tensile stress made in asphalt equals to the tensile strength is asphalt mixtures, a small fracture is made in edge and surface of asphalt, in lower temperatures the occurred fracture penetrates in all depth and width of asphalt layer. [12]

By literature review, it is understood that selecting the geometry and specifications of laboratory samples of asphalt fracture mechanic are significantly important. Many researchers have studied all various types of proper sample to test fracture in this field. Therefore, Majidazadeh et al. were the first ones who studied about selecting proper sample. [13] Aliha et al. (2013) studied the effect of each asphalt properties such as type of aggregation, type of aggregate, and type of tar based on the latest studies on asphalt fracturing resistance [28, 29]. They conducted fracture mechanics tests using SCB samples in very high number of samples. Aliha et al. tested their samples in -15°C to check low temperature thermal fractures and two siliceous and calcareous samples. The suggested the following results from their experiments using elastic fracture theory in various loading modes.

Li ad Marasteanu conducted semi-circle bending tests and fracture mechanics conceptions in two -30°C and -40°C to examine asphalt mixture in low temperature. In order to make flat bending mode, 3 asphalt samples with 25 mm thickness were prepared. The circular samples with 25mm thickness from the congested asphalt samples were prepared by gyratory compaction technique, which has 150mm thickness.

Ayatollahi et al. in their research examined various specification of asphalt such as aggregates, aggregation, tar types, and porosity percentage in various asphalt fracture modes. They used siliceous materials in 1,3,4, and 6 aggregation size of Iran regulation by considering various porosities to conduct mode 1 fracture test in low temperature. They used 5 aggregation sizes for their test. They concluded that fracture toughness of aggregation increased in mode II but decreased in aggregation no. 6. In addition, they concluded that fracture increases by increasing toughness [34]. Since Ayatollahi et al test was on asphalt fracture resistance in low temperature, temperature is one of effective parameters on SIF. The desirable temperatures for test are 0, -10, -20, and -30°C that asphalt has elastic properties in them. It can be found from the results of their research that SIF decreases by temperature decrease; however, this factor increases in temperature -10°C to -20°C. This is for exhaustion change in asphalt mixture from tar to the boundary of tar-aggregates, because tar strength increases by temperature decreases in a way that the exhaustion between tar-aggregates occurs. (14)

Considering the low temperature fractures in this research as the most important present fractures on asphalt pavements in the cold climates, they studied the effect of aggregates on asphalt fracture resistance. On one hand, fracture melting and glacial cycle as one of the most important factor of humidity sensitive was analyzed as an effective factor on asphalt fracture resistance. On another hand, using LEFM equations showed the effect of each main parameters of asphalt on fracture resistance or fracture toughness. It must be mentioned that humidity sensitivity was calculated by TSR criterion for research samples and their relationships with fracture toughness was examined. Consequently, simultaneous effect of melting and glacial cycle and type of consumed materials aggregates was studied on fracture toughness.

Methods and Materials

Various asphalt mixtures for laboratory plan were considered in this research for fracture mechanics tests. The used stone materials to prepare asphalt concrete mixtures must be clean and dust free. Coarse sand and aggregates are loader elements in asphalt mixtures, in this research, material, was used from two calcareous and siliceous materials were used to study one of the most important parameters. Calcareous stone materials were prepared from Asbcheran mine in Rudehen city and siliceous material was prepared from mine of Shahray Karaj city

Table (1): specifications of stone materials

Specifications	***Siliceous materials***	***Building lime***	***Limits***	
			Esther	***procedure***
Maximum wear by Los Angeles	14%	21.1%	40	30
The maximum ductility coefficient method BS812	8%	9%	30	25
The minimum percentage of fractures on both sides of the sieve (4)	92%	93%	80	90
The maximum water absorption of coarse aggregate	1.8%	2.1%	2.5	2.5
The maximum water absorption aggregate	1.3%	2.4%	2.8	2.8

In this research, the consumed tar was net tar type 60/70 prepared from Pasargad Oil Company. Various experiments were conducted on tar specifications, which are shown in table (2).

Table (2): Consumed tar specifications

Specifications	***Bitumen 60/70***	***Test***
Specific gravity at 25 ° C	1.02	ASTM D-70
Penetration at 25 ° C	63	ASTM D-5
Softening point (° C)	51	ASTM D-36
Gum plasticity at 25 ° C	104	ASTM D-113
Flash point	297	ASTM D-92

Materials aggregations were based on the present seize in Iran asphalt pavements routs regulations for No.4 (journal 234) aggregates. The element application and extensive laboratory application of this aggregate is the reasons of using this number.

Table (3) – aggregates No. 4, (journal 234)

Screen size (Mm)	***Rejected wt% of each sieve***	
	upper line	***Low***
19	100	100
12.5	100	90
4.75	74	44
2.36	58	28
0.3	21	5
0.075	10	2

Determination of Marshall resistance and versatility amounts of asphalt samples: after determination of the specific real weight of asphalt mixtures, samples put in full-water plate in 60°C for 30 min. Then, Marshal System gets warm and lubricated. After the determined time, samples were put inside system one by one, and then jack of loading Marshal system is inserted with 50.8 mm/min to samples, and maximum load on sample and maximum deformation by sample were recorded which were proposed as versatility . These two numbers were resistance and versatility of each sample. Resistance based on kg and versatility based on mm is recorded. After determination of the samples heights, Marshal resistance are modified based on reported ones in table of ASTM-D1559.

Rice test: Rice test was conducted to determine the porosity percentage and maximum specific weight of asphalt mixture, which are used to calculate the maximum specific of asphalt mixture. This test is conducted as warming two asphalt samples from different tar percentages, which are near to each other and consider for test. After warming and rushing them, they were put in 150gr in air evacuation containers to excavate air of sample completely. Then, it must be weighted accurately. Consequently, certain relations calculate the maximum specific weight of asphalt concrete.

Fracture test: in this part, experimental fracture test is explained. Calcareous and siliceous samples were put in refrigerator, respectively in -15°C for 24 hr. Fracture apparatus, as it is seen in figure (3-5), is transferred with 60 ton capacity transfers the inserted loads to it by the beneath connected fixture device and load-movement is recorded by computer. First, fixture is set to put fulcrums in proper places. According to experiment values, the distance of fulcrums from load insert place was 5 cm in mode 1. After fastening fulcrum, samples were put out, put on fulcrums, set on constant rate of 3 mm/min by computer. Results as load-movement diagrams were recorded after loading with the mentioned rate.

Modeling the samples software: in this research, finite element meshing is shown for 2800 eight-point elements in flat tension mode. Since materials are under 0°C, model is linear and homogenous elastic. Young's modulus and

Poisson's modulus for materials of SCB samples were considered 12500Mpa and 0.35 Mpa, respectively. For the modeled sample, load is inserted in the central axial point fir 1kN. Boundary conditions include replacement in two prohibited direction using the constraints in left and right fulcrums to prevent from vertical replacements in fulcrums. Finally, stress intensity factor (SIF) is calculated using ABAQUS software and line integral method. SIF is calculated for various fracture points having S_1 and S_2 and knowing fracture length. [29]

Findings

Many analyses were conducted on them after determination SIF and TSR amounts of laboratorial samples. In this research, the effect of each parameter is studied such as adding additives in asphalt mixture and thermal cycle effect.

One of effective factors on fracture resistance of asphalt mixtures is thermal condition of samples. In this research, there are two thermal cyclic and constant thermal conditions. Both samples made by calcareous and siliceous materials were tested in two dry and saturated modes to study the effect of thermal condition on tests results. The following results were obtained by ach test. As it is observed in figure (1) and (2), fracture resistance in constant temperature for siliceous materials was more than cyclic thermal condition. In addition, adding antistripping in cyclic thermal condition causes less fracture by coping with it in spite of significant effect of thermal condition in mode without modifier. It is noticeable that adding antistripping as modifier in less appropriate thermal condition increases humidity resistance and fracture resistance of asphalt samples, too. On the other hand, it can be concluded that adding antistripping modifier in cyclic thermal condition has less effect on samples fractures in various experimental modes (dry and saturated).

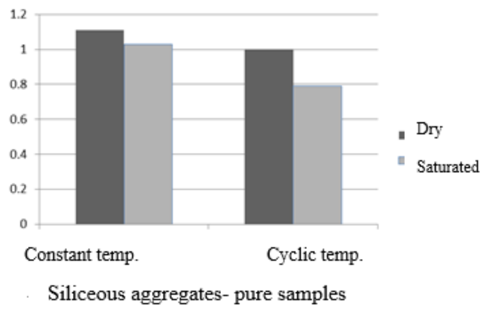

Fig (2) – effect of thermal condition in Siliceous aggregates- pure samples

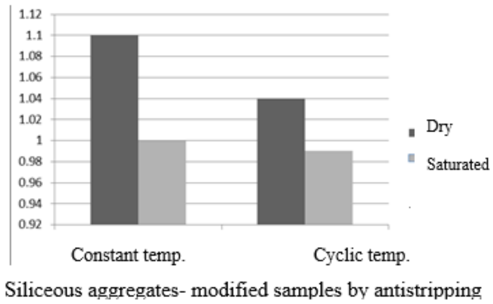

Fig (1) - effect of thermal condition in Siliceous aggregates and modified samples

Similar to the made asphalt mixtures by siliceous stone materials, the mountainous stone materials have similar procedures about thermal conditions effect. However, as it is seen in figure (3) and (4), adding antistripping modifier doesn't have significant effect on calcareous samples, because calcareous materials have proper fracture resistance themselves and the effect on antistripping is less tangible on them.

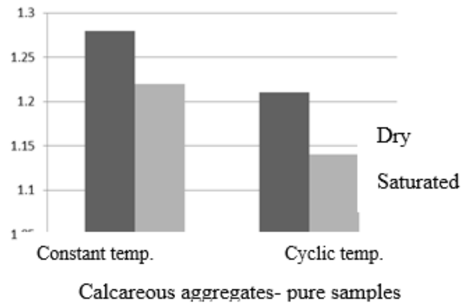

Fig (4) – effect of thermal condition in calcareous aggregates- pure samples

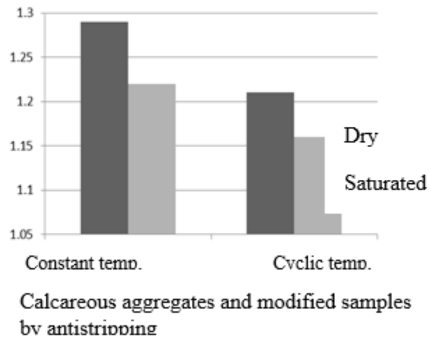

Fig (3) - effect of thermal condition in Siliceous aggregates and modified samples

One of important objectives of this research is studying the effect of stone material on fracture resistance and humidity sensitivity of asphalt mixtures. Therefore, both siliceous and calcareous groups were selected for experiments in various thermal conditions and using modifiers.

As it is observed in figure (5), the prepared asphalt mixtures in constant thermal conditions without using additives in calcareous samples have 15% more resistance than the siliceous samples. However, according to figure (6), both calcareous and siliceous samples lose resistance in cyclic temperature, but calcareous samples have still more resistance than siliceous asphalt mixtures; as though, calcareous fracture resistance in saturated mode is more than siliceous mixture fracture resistance in dry mode.

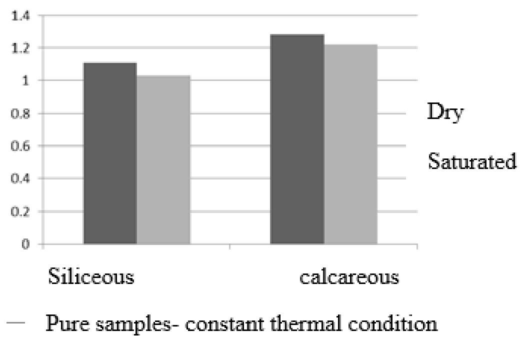

Fig (6) – effect of stone material type for pure samples in constant thermal condition

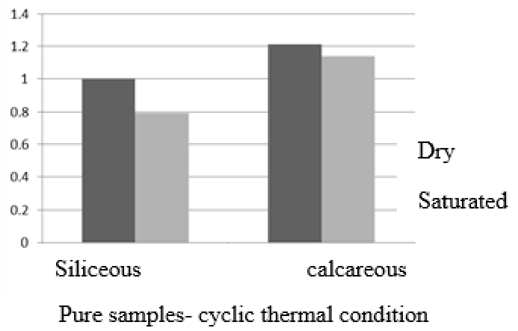

Fig (5) – effect of stone material type for pure samples in cyclic thermal condition

On the other hand, samples showed more resistance in dry mode for both materials. As it is seen in figure (7), fracture resistance of asphalt samples with calcareous Materials is about 20% more than fracture resistance of asphalt mixtures made by siliceous materials. On the other hand, by thermal changes from constant to varied temperature or cyclic temperature, mixtures resistance reduces, but fracture resistance for both materials were protected relatively and resistance procedure is constant with the similar thermal condition. According to figure (8), siliceous modified samples with antistripping have similar fracture resistance in both dry and saturated modes under the cyclic condition.

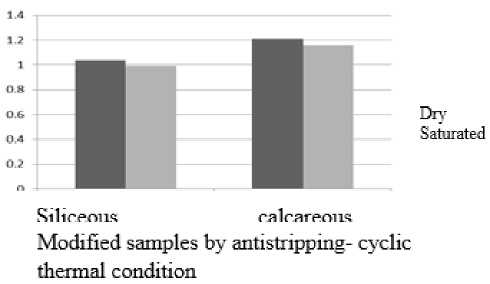

Fig (8) – effect of stone material type for modified samples by antistripping samples in cyclic thermal condition

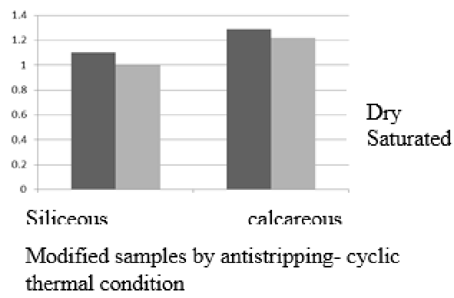

Fig (7) – effect of stone material type for modified samples by antistripping samples in constant thermal condition

One of objectives of this research is comparing the fracture criterion Ks/Kd with TSR criterion to determine the effectiveness of TSR criterion on asphalt samples resistance. On the other hand, fracture resistance of asphalt mixtures in dry and saturated modes can be considered as asphalt mixtures resistance criterion against humidity and freezing.

Therefore, various modes were examined. Siliceous samples in pure and without any additive forms in constant thermal conditions have higher stress than cyclic thermal condition. It can be concluded by comparing this value with TSR in similar condition that stress ratio is more than TSR in prepared mixtures. More proper values can be defined to replace TSR than constant thermal condition by observing the difference amounts of stress ratio with TSR for cyclic thermal condition. However, it is observed in figure (9) that the modified siliceous samples in cyclic thermal condition have more stress and significant difference from TSR. Consequently, adding additives to asphalt mixtures makes significant difference between fracture resistance ratio (TSR alternative) and TSR.

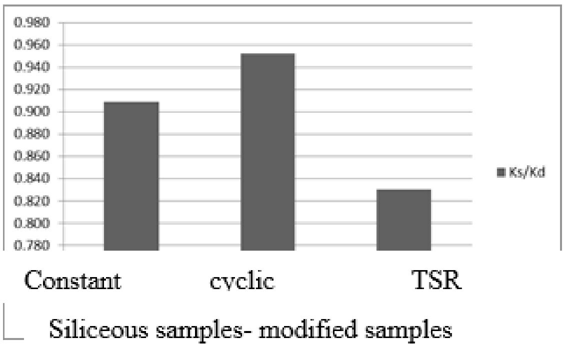

Fig (9) – comparison stress to TSR in pure siliceous samples

The prepared calcareous samples have similar procedure to siliceous samples in comparison between stress and TSR. According to low difference among TSR amounts and stress ratio, the stress ratio amounts can be sufficient as resistance against humidity sensitivity. As it was stated for the prepared siliceous samples, adding modifiers increases difference between stress ratio and TSR. TSR is 0.88 for calcareous materials by observing figure (10) and (11), while it is 0.94 with great difference in melting and thawing cycle than stress ratio and is 0.95 in constant thermal condition. Moreover, stress ration and also TSR amount is more in cyclic thermal condition with modifier than constant thermal condition. This means humidity sensitivity for the prepared samples with calcareous material has significant difference from fracture resistance.

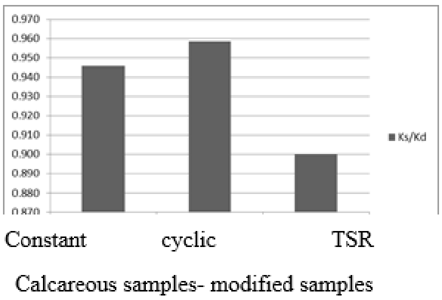

Fig (11) – comparison stress to TSR in pure calcareous samples

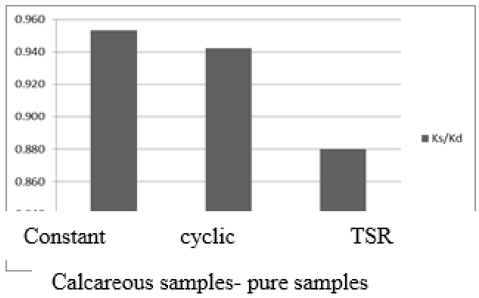

Fig (10) – comparison stress to TSR in pure calcareous samples

Conclusion

According to experiments and analyses in this research, the summary of the obtained results show that the modified samples with antistripping under the constant thermal condition have more fracture resistance for calcareous materials than the prepared siliceous samples. On the other hand, fracture resistance in constant temperature is more for siliceous materials than cyclic temperature. Fracture resistance decreases less in this mode. Fracture resistance of prepared asphalt mixtures in both thermal conditions are more in calcareous samples than siliceous samples. Adding additives to asphalt mixtures makes significant difference between fracture resistance (as TSR alternative) and TSR.

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