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Minimizing the Moisture Damage and Drain down of Iraqi SMA Mixtures Using Waste Additives

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Abstract

This research deals with the viability of using polyester fiber (PF), crumb rubber tire (CRT) and cellulose fiber (CF) as stabilizing waste additives in producing Iraqi SMA mixtures that sustain drain down phenomenon and moisture damage sensitivity. Different ratios of these additives (0.1, 0.2, and 0.3% by weight of aggregate and filler) were mixed with 40/50 paving asphalt by means of dry process. Unmodified and modified SMA mixtures were subjected to drain down, Marshall, static indirect tensile strength, tensile stiffness modulus, static compressive strength, tensile strength ratio and index of retained strength tests. A set of regression equations between these tests were established. In addition, an optimization table based on these tests, which can be used to select the type or amount of additive for any field applications has been determined and reported. The results indicated that the inclusion of these additives in SMA mixtures can satisfy the performance requirement of high temperature and much rain zone.

Keywords: Additives; Stone matrix asphalt; Waste materials; Scrap tires; Optimization.

استخدام مخلفات المواد كمضافات لتقليل ظاهرة النزيف وتأثير الماء على الخلطات الاسفلتية نوع SMA

الخلاصة

يتحرى البحث عن امكانية استخدام مخلفات البوليستر فايبر ومسحوق الاطارات وقش ال الح كمواد مثبتة في انتاج الخلطات الاسفلتية نوع SMA تقاوم ظاهرة النزيف وتاثير الماء. عدة نسب (0.1,0.2، 0.3%) من وزن الركام والفلرتم مزجها مع الاسفلت نوع 40−50. اجريت فحوصات المارشال،مقاومة الشد،صلادة الشد،مقاومة الانضغاط، نسبة المقاومة المتبقية من فحص الشد ودليل المقاومة المتبقية من فحص الانضغاط على الخلطات غير المطورة والمطورة.كونت العديد من المعادلات الرياضية بين الفحوصات التي تم اجرأؤها. اضافة الى ذلك وبالاعتماد على الفحوصات تم اعداد جدول يمكن من خلالة اختيار نوع وكمية المضاف لأي تطبيق حقلي.أوضحت النتائج ان وجود مثل هذه المضافات يفي بمتطلبات الخلطات الاسفلتية تجاه مقاومتها للحرارة العالية وتأثير الماء.

الكلمات الدالة:مضافات ، SMA، مخلفات المواد، مسحوق الاطارات، الامثلية

Symbols

AC: Asphalt concrete.
CF: Cellulose Fiber.
CRT: Crumb Rubber Tire.
HMA: Hot Mix Asphalt.
IRS; Index of Retained Strength.
LDPE: Low Density Polyethylene.
MQ: Marshall Quotient.
OGFC: Open Graded Friction Courses.
p: Significant.
PF: Polyester Fibber.
PMAC: Polymer Modified Asphalt Concrete.
PP: Polypropylene.

r: Pearson correlation coefficient.
SBS: Styrene–Butadiene–Styrene block copolymer
SCDOT: South Carolina Department of Transportation.
69 SMA: Stone Matrix Asphalt
Starch: ST
TSR: Tensile Strength Ratio.

Introduction

In some parts of Iraq, the disposal of waste materials such as fibers and tires produced from numerous manufacturing processes is an economical and environmental problem for companies and municipalities (e.g., cost, landfill space, etc.). These materials are sometimes used in other applications, but commonly they are disposed of in landfills. Fibers and tires wastes are produced from the tire processing industry in Babylon (200 km south Baghdad Capital), whereas, If these wastes could be beneficially utilized in any application, it would reduce the burden on diminishing landfill space. Also, using such waste materials could be economically beneficial compared to fibers manufactured for a specific application.

Processing scrap tires involves the shredding and/or grinding of the tires into smaller particles called crumb rubber. A typical tire contains approximately 60% rubber, 20% steel, and 20% fiber. The crumb rubber is used for many applications ranging from rubberized asphalt to playground construction. The steel is typically sold to steel manufacturers where it is recycled. However, in most cases the polyester fibers have no specific end use and are disposed of in landfills. For instance, four tractor trailer loads of scrap tire fiber are hauled to the landfill every month from Babylon industry.
70 With approximately 20,000,000 tires processed into crumb rubber each year, that makes for an abundance of fiber that is going to waste.

In the production of fabrics such as headliners, seat backs, and door panels there is a waste stream resulting from the process of shearing the woven fabrics to size. This shearing process creates waste in the form of fine polyester particles that are collected and form tufts of lint. A small portion of this lint is recycled, but yet most of this waste is disposed of elsewhere.

Fibers have been used in asphalt mixtures for two main reasons: (1) to increase the toughness and fracture resistance of hot mix asphalt (HMA); and (2) to act as a stabilizer to prevent drain down of the asphalt binder (Bradley and Serji, 2004)[1]. There has been limited use of fibers to increase toughness, even though research has shown that the addition of polyester fibers does increase the toughness of asphalt mixtures (Freeman et al., 1989) [2]. Fibers, such as cellulose and mineral fibers, have been used in large part as a stabilizer in such asphalt mixtures as stone matrix asphalt (SMA) and open graded friction courses (OGFC).

Stone matrix asphalt was developed in Europe in the 1970s as a rut resistant asphalt mixture. This type of rut resistant mixture has been used by several states in the US since 1991 and its popularity is growing (Brown et al., 1997) [3]. SMA is defined as a HMA prepared with a gap-graded aggregate gradation in order to maximize the asphalt binder content and coarse aggregate fraction (Brown, and Cooley, 1999) [4]. The large coarse aggregate fraction provides rut resistance through stone-to-stone contact, while the high binder content (typically 5.5–7.0% by weight of mixture) provides durability through an increased film thickness around the aggregate particles. Due to these advantages the Ministry of Housing and Construction in Iraq decided to introduce SMA in its road specification to control or limit the distress failure in most provinces such as rutting, shoving, stripping etc. through additive modification.

In order to obtain such a high binder content without excessive drain down, mineral filler and stabilizers are added to the mixture. Examples of mineral fillers include fly ash, hydraulic cement, hydrated lime, and rock dust, which all have a high percentage of particles passing the 75µm sieve (55–100%). Polymer modified asphalt binders are typically used in the production of SMA mixtures due to their rut resistant properties. The increased viscosity of these binders is also beneficial to minimize drain down in the mix. To further aid in the reduction of drain down, fibers are typically included in SMA mixtures as a stabilizing additive. The most common types of fibers used in SMA include cellulose and mineral fibers. Some of these fibers, depending on the source, could be relatively expensive.

Moisture damage and permanent deformation are the primary modes of distresses in hot mix asphalt (HMA) pavements in most Iraqi provinces. The performance of HMA pavements is related to cohesive and adhesive bonding within the asphalt–aggregate system. The loss of cohesion (strength) and stiffness of the asphalt film, and the failure of the adhesive bond between aggregate and asphalt in conjunction with the degradation or fracture of the aggregate were identified as the main mechanisms of moisture damage in asphalt pavements (Terrel and Al-Swailmi, 1994; Cawsey and Raymond, 1990) [5,6].

The loss of adhesion is due to water leaking between the asphalt and the aggregate and stripping away the asphalt film. The loss of cohesion is due to the softening of asphalt concrete mastic at high temperature. Moisture damaged pavement may be a combined result of these two mechanisms. Further the moisture damage is a function of several other factors like the changes in asphalt binders, decreases in asphalt film thickness, changes in aggregate quality, increased widespread use of selected design features, and poor quality control (Epps et al., 2000; Sengoz and Agar, 2007) [7,8]. Moisture susceptibility of hot mix asphalt (HMA) pavements continues to be a major pavement distress. As moisture damage reduces the internal strength of the HMA mix, the stresses generated by traffic loads increase significantly and lead to premature rutting, raveling and fatigue cracking of the HMA layer (Kandhal, 1992)[9].

Additives have been used for improving performance of HMA pavements to various distresses (i.e., permanent deformation, moisture damage, and fatigue or low-temperature cracks). There are numbers of different additives available, which can be introduced directly to the asphalt cement as a binder modifier, or can be added to the mixture with the aggregate (Roque et al., 2005) [10]. The use of hydrated lime or other liquid anti-stripping agents are the most common methods to improve the moisture susceptibility of asphalt mixes. Lime enhances the bitumen–aggregate bond and improves the resistance of the bitumen itself to water-induced damage. Researches have indicated that the amount of hydrated lime needed to improve the moisture sensitivity of hot mix asphalt is 1–2% by dry weight of aggregate (Paul; Jones, 1997) [11, 12]. Some mixture may require lime contents as high as 2.5% to achieve the desired results (Little and Epps, 1993) [13]. The studies showed that the hydrated lime appeared to perform better than liquid antistrip agents and indicated that the antistripping additives showed significant effect on reducing moisture damage (Maupin, 1995; Abo-Qudais and Al-Shweily, 2007) [14, 15].

Polymers, which are the most commonly used additives in binder modification, can be classified into four main categories, namely plastics, elastomers, fibres and coatings. To achieve the goal of improving bitumen properties, a selected polymer should create a secondary network or new balance system within bitumens by molecular interactions or by reacting chemically with the binder. The formation of a functional modified bitumen system is based on the fine dispersion of polymer in bitumen for which the chemical composition of bitumens is important (Isacsson and Lu 1995) [16]. Among polymers, the elastomer styrene–butadiene–styrene (SBS) block copolymer is the most widely used one. It has been identified that SBS triblock copolymer can obviously improve the mechanical properties of mixtures such as ageing (Cortizo et al., 2004) [17], permanent deformation (Tayfur et al., 2007; Vlachovicova et al., 2007) [18, 19], low temperature cracking (Isacsson and Zeng, 1997) [20], moisture damage resistance (Shuler and Douglas, 1990; Won and Ho, 1994) [21, 22], and so on.

Recently, Al-Hadidy and Tan (Article in press) [23] found that the addition of 5% Starch (ST) and 5% SBS raised the tensile strength ratio (TSR) of the control mix by 38% and 12%, respectively. Their results indicated that these modifiers do not cause the mixture to weaken when exposed to moisture. In addition, they stated that ST can be used as anti-stripping agent instead of other known types such as; coconut oil ethanolamine, Wetfix I, Lilamin VP75P, Chemcrete, and hydrated lime.

Awanti et al (2008) [24] found that the Marshall stability and flow values of polymer modified asphalt concrete (PMAC) mixture are higher when compared to asphalt concrete (AC) mix at optimum binder content. The static indirect tensile strength values for PMAC mixtures were higher when compared to AC mixes at different temperatures. Moisture susceptibility of PMAC mixtures is low when compared to AC mixtures.

Al-Hadidy and Tan (2009) [25] investigated the benefits of modifying the SMA mixture in flexible pavement. AH-50 and four proportion of polypropylene (PP) were selected. The performance tests including, Marshall stability, tensile strength and compressive strength were conducted on unmodified and modified SMA mixtures. The regression relationships between the performance tests were obtained. The analyses of test results show that the performance of PP-modified asphalt mixtures are better when compared to conventional mixtures. The temperature susceptibility can be reduced by the inclusion of PP in the asphalt mixture. The percentage decrease in the stripping values of about 44 and 2%, respectively, for asphalt and modified binder containing 5% PP.

Al-Hadidy and Tan (2009) [26] investigated the potential use of low density polyethylene (LDPE) as a modifier for asphalt paving materials. Its effect on the moisture sensitivity of SMA mixtures was studied. The results indicated that the inclusion of LDPE in SMA mixtures can satisfy the performance requirement of much rain zone (i.e. increase the adhesion between aggregate and asphalt, which leads to a decrease in the stripping of SMA).

Tikrit Journal of Eng. Sciences/Vol.18/No.3/September 2011, (68-80)

Tests for evaluating the stripping potential may be divided into two types. The first is tests to which visually estimate stripping that measures the time-to-disruption of mix specimens stressed in some manner in the presence of water and the second is tests which measure the change in mechanical properties of mix specimens exposed to water in some type of conditioning scheme (Atakan et al., 2005) [27]

The focus of this research is:

1. Possibility of using the South Carolina Department of Transportation (SCDOT) (Bradley and Serji. 2004) [1] 13 mm SMA gradation on the Iraqi paving materials.
2. Using additives in SMA to produce paving mixtures that resist the action of temperature and temperature changes, the action of air and water and the action of traffic.
3. Evaluation of the moisture induced damage of SMA mixtures using two testing procedures, namely the unconditioned and conditioned direct compression and indirect tensile strength, and select which one is the most promising.
4. Visibility of using waste additives as a stabilizing in SMA mixtures.
5. Prepare an optimization table based on the performance measures, which can be utilized to select the type or amount of additive for any field applications; and
6. Establish regression equations between the performance measures (Marshall stability, indirect tensile strength, tensile stiffness modulus and compressive strength at dry and wet state) for situations in which: a) the indirect tensile and/or compressive strength tests were not available, and /or b) the designer does not choose to use those tests, and /or c) the tensile stiffness modulus is not available.

The additives used in this research are crumb rubber tire (CRT), polyester fiber (PF) and cellulose fiber (CF). Those additives were chosen for the following reasons: it a waste materials and it require a low percentage added to mixture.

In our tests these additives have not been added to the binder but to the granular skeleton. Asphalt without additive was mixed using the same procedure as a reference test. Nine SMA mixture groups were prepared and tested, each of CRT and PF having 75 specimens, and CF having 50 specimens. Thus, performance measures evaluated on the 200 specimens containing additives regarded.

Experiments

Material selection

One type of aggregate, one type of asphalt binder and three types of additives as mentioned earlier were selected for the present study. Table 1 shows the recommended gradation limits by the SC DOT (Bradley and Serji. 2004) [1] for SMA mixtures and the selected gradation in this research was in the middle of the limits. The physiochemical properties of asphalt cements as per ASTM (2002) [28] are presented in Table 2. Calcium carbonate ($CaCO_3$) was used as mineral filler. It was passed through a 200 sieve and had specific gravity of 2.731. PF included in this study was 5 denier obtained from recycled raw materials. It was cut to 7.20mm in length and had a specific gravity of 1.33±0.03. PF was used in different percentages of 0.1, 0.2 and 0.3% by dry weight of aggregate and filler. CRT passed a 6.3mm sieve obtained from grinding of the tires in Babylon industry that was used in different percentages of 0.1, 0.2 and 0.3% by dry weight of aggregate and filler. The gradation of CRT is presented in Table 3. CF was 1.1mm in length and had a specific gravity of 0.028±0.005. CF was used in two percentages of (0.1 and 0.2) % by dry weight of aggregate and filler.

Optimization of the mixtures

The mix design procedure for SMA as proposed in NCHRP report No.425 (1999) [4] was followed in performing the mix design to be used. In SMA mix design, usually the Marshall method of mix design is used to verify satisfactory voids in SMA mixtures. Laboratory specimens were prepared using fifty blows of the Marshall hammer per side. Seventy-five compaction blows were not used since they would not result in a significant increase in density over that provided by 50 blows. SMA mixtures have been more easily compacted on the roadway to the desired density than the effort required for conventional HMA mixtures (ASTM, 2002) [28]. The optimum asphalt content for SMA mixtures is usually selected to produce (3-5) % air voids and a drain down of less than 0.3%. The optimum asphalt content for the control SMA mixture was found to be 6.0% at 4.1% air voids. To obtain the consistency through the research all specimens were prepared at this optimum asphalt content. In addition, the percentage of additives used was selected that satisfy a drain down range of 0.25 to 0.3% by weight of total mixture and tensile strength ratio (TSR) greater than or equal 85%, since the control mixture satisfies the design requirements of stability and air voids.

Laboratory testing

The performance tests including, Marshall stability, static tensile strength, tensile stiffness modulus and static compressive strength were conducted on unmodified and modified SMA mixtures according to ASTM (2002) [28].

Results and discussion

Statistical considerations

Results of the drain down, Marshall, indirect tensile, TSR, tensile stiffness modulus, compressive strength and index of retained strength (IRS) tests were statistically analyzed with a 5% level of significance. For these comparisons, it should be noted that all specimens were produced at optimum asphalt content.

Drain down

Drain down test using wire basket method as proposed in the NCHRP Report No.425 (1999) [4] was run on all the mixtures evaluated. In this test, the laboratory-prepared loose mixture was placed in a forced draft oven for 1h at a pre-selected temperature of 165^{o}C. At the end of 1 h, the basket containing the sample is removed from the oven along with the plate and the mass of the plate was determined. The amount of increased weight of the plate is the amount of drain-down of the mixture. As specified in NCHRP (1999) [4], the oven temperature for performing the drain down test should be at the mixing temperature and/or the mixing temperature plus 15^{o}C.Thus, an oven temperature of 165^{o}C was used for the unmodified and modified mixtures. The results of the drain down test were summarized in Fig. 1. From this plot, it can be observed that the values of drain down for conventional, 0.2%CRT, 0.19%PF and 0.18% CF-modified asphalt concrete samples are 0.33, 0.282, 0.282 and 0.244, respectively. The potential effects of the inclusion of these additives in SMA mixtures are therefore beneficial in preventing bleeding phenomenon of the SMA mixtures. No mineral fiber was needed to prevent drain-down when additives were used, and at the same time CRT and CF can be used as a stabilizing instead of mineral fiber.

Tikrit Journal of Eng. Sciences/Vol.18/No.3/September 2011, (68-80)

Marshall properties

Three specimens of unmodified and modified mixtures were prepared at the optimum asphalt content of 6.0%, to determine the Marshall properties. Marshall test results were summarized in Fig. 2.

From the sited results in Fig. 2, it was found that the Marshall Quotient (stability/flow) (MQ) value increased by 6.6%, 48.9% and 45% at 0.2% CRT, 0.19% PF and 0.18% CF content, respectively. It can be said that these additives-modified SMA mixtures provide better resistance against permanent deformations due to their high stability and high MQ.

Moisture damage

Resistance to moisture and effect of additives on moisture-induced damage of SMA mixtures were evaluated by using TSR (warm-water soaking 24h at 60^0C followed by 2h at 25^oC) and IRS (warm-water soaking 24h at 60^0C followed by 2h at 25^oC).

One hundred-eight specimens of unmodified and modified mixtures were prepared to determine the tensile and compressive strength values. These specimens were divided into two groups (Fifty-four specimens each).The two groups of 101.6mm diameter x 63.5mm tall specimens were compacted to 6-8% air voids with a Marshall hammer. First set is tested at 25^0C in both indirect tensile and compressive strength. The second group of specimens was placed in water bath at 60^oC for 24h, followed by 2h at 25^oC and tested. The load at failure was determined. All tensile strength and compressive strength test results were related to a deformation rate of 50.8 mm/min. and 0.05 mm/min. mm of height or 3.2 mm/min for Marshall specimen, respectively. The tensile strength and tensile stiffness modulus of specimens was determined using the formulas mentioned by Lottman (1970, 1978) [29, 30]. The TSR and IRS are calculated as the ratio of preconditioned strength to dry strength. The minimum wet tensile strength and TSR necessary to ensure good pavement performance has been identified in SCDOT (Bradley and Serji, 2004) [1] and found to be 448 kPa and 85%, respectively. Mixtures with TSR less than 85%are moisture susceptible and mixtures with ratios greater than 85% are resistant to moisture damage.

Tensile strength and TSR for additives modified mixtures are given in Fig. 3, respectively. The results indicate that tensile strength, tensile stiffness modulus and tensile strength ratio increased for both testing temperatures (i.e. increase the adhesion between aggregate and asphalt, which leads to a decrease in the stripping of SMA). Tensile strength for additives-modified asphalt mixtures is slightly higher than for conventional asphalt mixtures. Test results indicated that the percentage increase in TSR values of about 36.3, 36.8, 41.8%, respectively, for modified mixtures containing 0.2%CRT, 0.19%PF and 0.18%CF using Al-Kazer aggregate. It can be seen that these additives improve the resistance to moisture susceptibility of the asphalt mixtures.

The variation of the compressive strength and IRS and different type of SMA mixtures was illustrated in Fig. 4, respectively. From Fig. 4, it can be observed that the ranges of compressive strength for conventional, 0.2%CRT, 0.19%PF and 0.18%CF-modified asphalt concrete samples are 5066.2 kPa to 4082 kPa, 3302.3 kPa to 3246 kPa, 5856 kPa to 5174 kPa and 4081 kPa to 4934.2 kPa at 25 and 60°C, respectively. The percentage increase in the averaged compressive strength is found to be comparatively significant. The study showed that the IRS of the control SMA mixture was increased by 17.7, 7.8 and

Tikrit Journal of Eng. Sciences/Vol.18/No.3/September 2011, (68-80)

40.3% at 0.2%CRT, 0.19%PF and 0.18%CF content, respectively.

Regression equations

A one-way ANOVA was performed to correlate regression equations between the performance measures (Marshall stability, indirect tensile strength, tensile stiffness modulus, and compressive strength). The equations for each additive type are summarized in Table 4, and generally show higher Pearson correlation coefficient (r) and lower significant (*p*) values. These equations were developed for situations in which: a) the indirect tensile and/or compressive strength tests were not available, and /or b) the designer does not choose to use those tests, and /or c) the tensile stiffness modulus is not available.

Optimization of additives modified-SMA mixtures

SPSS statistical analysis program V.16 was used to prepare an optimization table based on the performance measures conducted on additives modified SMA mixtures. Duncan correlation was selected to determine the significant between groups .This significant was defined by addition a letter(s) for each group. If the letter(s) shared between two groups or more, this indicates that no significant can be found between groups. Results obtained from such analysis are summarized in Table 5. Table 5 can be used to select the type or amount of additive for any field applications. Actual selecting would depend upon the option exercised by the designer.

Conclusions

Based on this limited study of the utilization of PF, CRT and CF additives in SMA mixtures, the following findings were made:

1. The additives were effective in preventing excessive drain down of the SMA mixtures (i.e. bleeding phenomenon).
2. It was found that PF and CF can be used as stabilising agents in SMA mixtures, at the rate of 0.19% and 0.18% by weight of mixture, respectively. This indicates that the typical rate (0.3-0.4%) of mineral fibers stabilization has been reduced by (38-54%).
3. Marshall results indicated that 0.2%CRT, 0.19%PF and 0.18%CF raised the stability of control mixture by 11%, 22% and 30%, respectively. It can be said that additives-modified SMA mixtures provide better resistance against permanent deformations due to their high stability and high MQ.
4. The mixtures containing these additives greatly exceeded the minimum wet tensile strength of 448 kPa set by the SC DOT.
5. The TSR for the mixtures containing 0.2% CRT, 0.19%PF and 0.18%CF were increased by 36.8, 36.8 and 41.8%, respectively. This indicates that these types of additives do not cause the mixture to weaken when exposed to moisture.
6. Based on the observations and the analysis of the results using a statistical program; indirect tensile strength test was the most promising for evaluation the moisture induced damage of SMA mixtures.
7. Based on a one-way ANOVA analysis, linear regression equations could be adequate for determination the performance measures (indirect tensile and compressive strength) of SMA modified with the proportion of additives (by weight) ; and
8. An optimization table based on the performance measures, which can be used to select the type or amount of additive for any field applications has been determined and reported.

9. Utilizing of these wastes in pavement application could be beneficially, it would reduce the burden on diminishing landfill space. Also, using such waste materials could be economically beneficial compared to fibers manufactured for a specific application.

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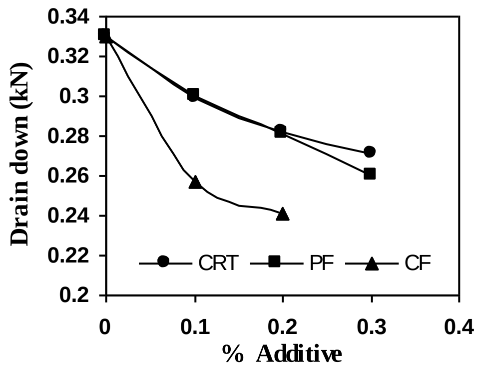


Fig. 1 Effect of additives on drain down

Fig. (2-c) Effect of additives on drain down

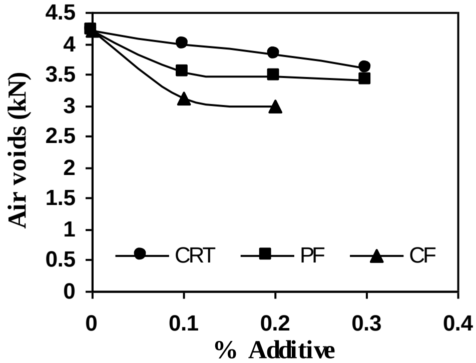


Fig. (2-a) Effect of additives on drain down

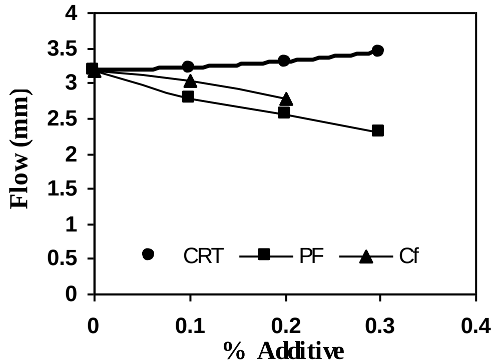


Fig. (2-d) Effect of additives on drain down

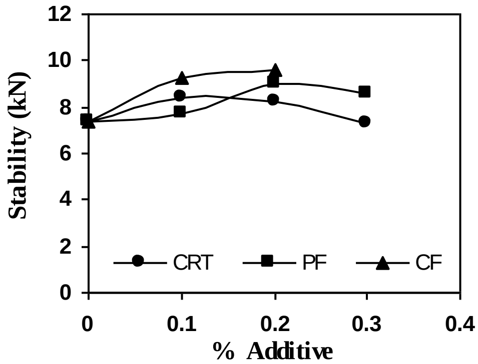


Fig. (2-b) Effect of additives on drain down

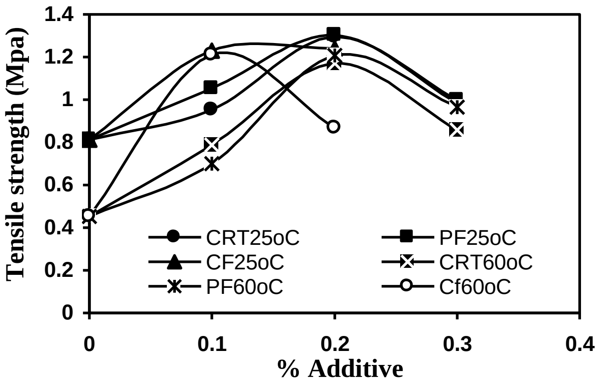
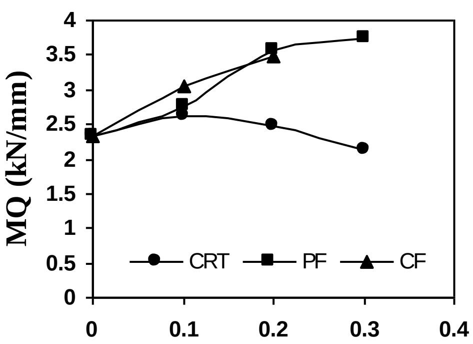
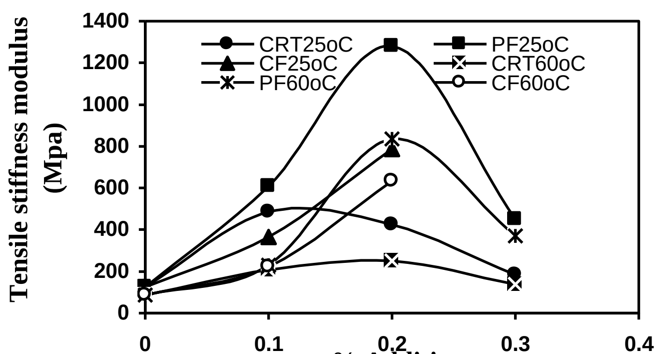


Fig. (3-a) Effect of additives on tensile strength properties





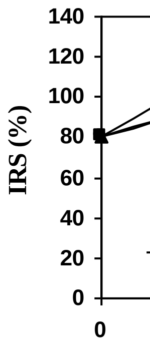


Figure. (3-b) Effect of additives on tensile strength properties

Figure. (4-b) Effect of additives on compressive strength properties

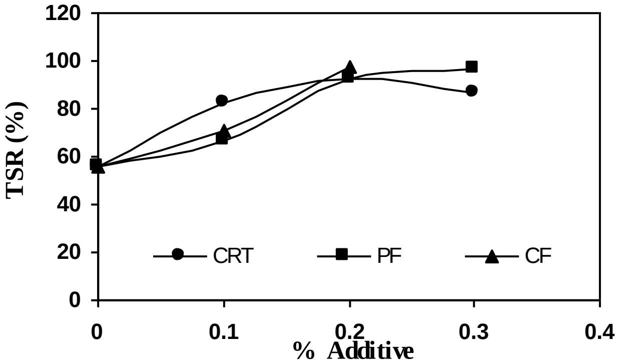


Figure. (3-c) Effect of additives on tensile strength properties

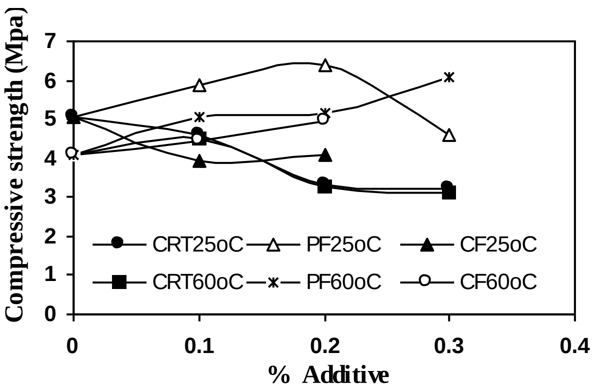


Fig. (4-a) Effect of additives on compressive strength properties

Table (1) Gradation of aggr

Sieve size (mm)	% passing	Job m
25.4	100	
19.0	100	
12.5	85-90	
9.5	60-80	
4.75	25-32	
2.36	18-24	
0.6	12-20	
0.3	9-15	
0.075	8-12	