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# Evaluation of Moisture Sensitivity Performance of Stone Mastic Asphalt Mixes with Additional Filler: A Laboratory Comparison of Dry and Wet Mixing Methods

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Gap-graded mixtures are one of the areas of improving the permanent deformation strength of hot-mixed asphalt mixtures. Additional filler materials can be needed due to the high bitumen amount and the less fine aggregate amount in the mixture. In this study, the effects of filler additives on moisture susceptibility of the gap-graded hot-mixed asphalt mixtures and mixing methods are investigated. Filler additives such as class C and class F fly ashes and hydrated lime are used 0.5%, 1.0 %, 2.0 %, and 4 % of the total weight of mixture instead of mineral filler. Design mixtures are prepared according to the Turkish Highway Technical Specifications (THTS). To determine the effect of mixing methods, dry and wet (slurry) methods are used to mix the filler materials. Modified Lottman method (AASHTO T283) are used to determine the moisture susceptibility. An indirect tensile strength test is the measurement of bitumen film thickness which is also conducted. Test results showed that class C fly ash is significantly improved the moisture susceptibility of mixtures. While the slurry method does not give the expected improvement on class C fly ash added mixtures, it shows a positive effect on class F fly ash and hydrated lime added mixtures.

*Keywords:* fly ash, hydrated lime, moisture susceptibility, stone mastic asphalt.

## 1. INTRODUCTION

Stripping resulting from weakening adhesive bonding between aggregate and bitumen due to the moisture damage can be most often seen on the bituminous pavement. Moisture also causes the weakness of cohesive bonding in the bitumen. Moisture damage decreases the strength of asphalt mixtures causing deterioration such as rutting and cracking on the asphalt pavement [1]. Besides climate and traffic effects, the properties of asphalt mixtures have also an important effect on moisture damage of asphalt mixtures. Additive materials can be used to improve adhesion between bitumen and aggregate and to reduce moisture damage of asphalt mixtures. Many chemical liquid antistripping additive materials used for this purpose are the family of amines or amidoamines [2, 3]. Additives are developing and testing against stripping due to water damage. Amines based developed liquid antistripping agents improve rutting resistance and stripping of asphalt mixtures [4, 5].

Some appropriate materials can also be used to decrease the hydrophilic properties of aggregates by coating. Mineral powder (passing from 0.063 mm sieve size) filler improves some negative properties between aggregate and bitumen [6]. Filler materials fill the voids within the asphalt mixtures and thus impermeable structure occurs. Portland cement used as a filler material increases the strength of asphalt mixtures against water absorption [7]. Fly ash used as a mineral filler improves the water strength of hot-mixed asphalt mixtures [8]. Lime is widely used among them. Hydrated lime can be used 1 – 2 % of total aggregate weight as a filler material in the asphalt mixtures [9 – 12]. While hydrated lime can be mixed with aggregate either dry or wet and mixed as a slurry. Hydrated lime is widely and effectively used mixing with wet aggregate or by slurry form [13]. It is proven that hydrated lime significantly changes the rheological properties of asphalt mixtures. Many experimental results showed that the addition of hydrated lime to the asphalt mixtures improves the moisture damage strength when it must be subjected to wet-dry process [14, 15]. Many researchers indicated that hydrated lime also improves moisture strength and adhesion between the aggregate and bitumen [16 – 18].

Recently, fly ash using as an alternative filler additive has a great interest in the area of asphalt pavement. The reason for this, fly ash is more economical and workable than hydrated lime. Fly ash produced from the thermal power plants is difficult to dispose and it costs much many to make a regular disposal area. Using fly ash in the asphalt mixtures gives benefits to the environment and reduces the waste material amount. When fly ash is used instead of mineral filler, it improves rutting and moisture damage. Fly ash having free lime and hydrophobic nature decreases the potential stripping of asphalt mixtures. Asphalt pavement mixtures same as SMA have coarse gradation to carry intensive and heavy traffic loads. Therefore, fly ash used as a mineral filler is needed to make the mixture hard and to reduce bitumen drain down [19].

Some previous studies showed that the addition of fly ash improves the performance of hot-mixed asphalt mixtures. Adding 3 – 6 % fly ash to the asphalt mixture gives comparable results to the other antistripping agents against moisture damage [20]. It is reported that fly ash also works as a hardener and void filler [21, 22]. Ali et al. [23] indicated that fly ash added 2 % of the total weight of aggregate to the asphalt mixtures improves not only

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stiffness properties but also strength and stripping resistance of mixtures. Huang et al. [24] added 1.0 % class F fly ash to the asphalt mixtures. He obtained similar resilient modulus results compared to that of control specimens. However, the resilient modulus values of fly ash mixed samples are lower than that of lime mixed samples. According to the indirect tensile test results, the tensile strength of fly ash added samples has 15 % higher than that of control specimens. However, the tensile strength of lime added samples has 25 % higher than that of control specimens.

SMA is a gap-graded bituminous hot mixture and is popular around the world. SMA is first developed in Germany in the 1960s and is widely used due to the high potential resistance to permanent deformation or rutting since the 1990s [25]. However, the evaluation of SMA against stripping and moisture damage is limited. SMA has not only gap graded structure but also fewer fine materials. Therefore, it needs stabilization to prevent bitumen drainage. This can be done by adding modifiers such as fibres or polymers to the mixture [26].

Adhesion between aggregate and bitumen is becoming important due to the high coarse aggregate ratio in the SMA mixtures. Filler additives are needed due to the decreasing fine materials in the SMA mixtures. At this point, filler additives chosen as a function in terms of moisture damage used in the SMA mixtures have some positive effects, extending service life, against moisture damage. To decrease moisture damage, fly ash obtained from thermic power plants is known as an effective filler additive and also using fly ash is economical for Turkey and the World.

In this study, the effects of filler additives are investigated against moisture damage of gap-graded hot-mixed asphalt mixtures. Class C and class F fly ash considering lime content and pozzolanic properties are considered as an alternative to the hydrated lime used against water damage. The effects of fly ash (class C), which contains a high amount of quick lime, are compared to that of other filler additives. The effects of filler additives amount, and mixing methods (dry and wet) are also investigated. The effect of the commercial antistripping agents is also investigated against moisture sensitivity. Samples are prepared according to Turkish Highway Technical Specifications and compacted by using a Gyratory compactor. Nicholson stripping test and AASHTO T283 [27] method is used to determine moisture susceptibility. An indirect tensile strength test is carried out to determine the bitumen film thickness.

## 2. EXPERIMENTAL DETAILS

### 2.1. Materials

One type of aggregate and bitumen was used to design SMA mixtures. The cellulosic fibre was used to stabilize bitumen in the mixtures. Class C and F fly ashes and hydrated lime were used as a filler additive. Some properties of crushed limestone aggregate are given in Table 1. Specific gravity and water absorption values of aggregate were given in Table 2. Grain size distribution of aggregate, including upper and lower limit specifications for SMA Type-1, are given in Fig. 1. B 50/70 bitumen class was used in the production stages of all the specimens since it is frequently chosen in many applications of hot mix bituminous binder due to the climatic conditions of Turkey. Some properties of bituminous binder are given in Table 3.

**Table 1.** Physical properties of crushed limestone aggregate

| Characteristics | Standards | Values | Spec. limits |
|---|---|---|---|
| Los Angeles abrasion, % | TS EN 1097-2 | 18 | < 25 |
| Sodium sulfate soundness, % | TS EN 1367-1 | 0.85 | < 14 |
| Crushing value, % | TS EN 933-5 | 100 | < 25 |
| Flakiness index, % | TS EN 933-3 | 7.8 | 100 |
| Polished stone value | EN 1097-8 | 53.1 | > 50 |
| Stripping resistance, % | EN 12697-11 | 45-50 | > 50 |

**Table 2.** Specific gravity and water absorption values of aggregate fractions

| Aggregate fractions | Standards | App.spec. gravity | Bulk spec. gravity | Water abs., % |
|---|---|---|---|---|
| Coarse aggregate | TS EN 1097-6 | 2.863 | 2.795 | 0.39 |
| Fine aggregate | TS EN 1097-6 | 2.881 | 2.796 | 1.54 |
| Filler | TS EN 1097-7 | 2.786 | – | – |

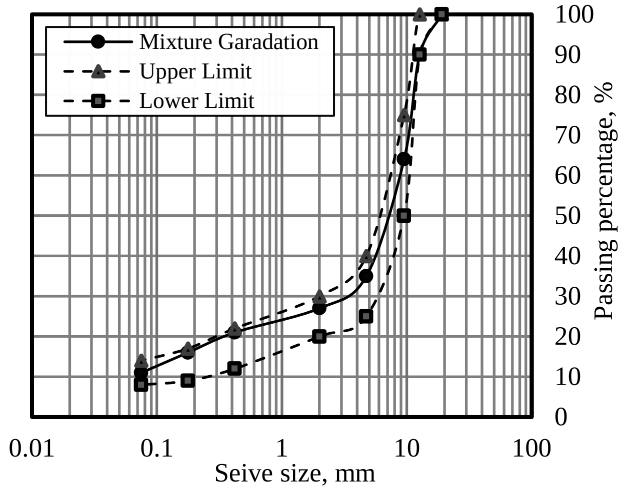


**Fig. 1.** Aggregate gradation and specification limits for SMA mixture

**Table 3.** Physical characteristics of bituminous binder (B 50/70)

| Properties | Standards | Results | Limits |
|---|---|---|---|
| Penetration at 25 °C, 0.1 mm | TS EN 1426 | 65 | 50 – 70 |
| Softening point, °C | TS EN 1427 | 49.2 | 46 – 54 |
| Flash point, °C | TS EN ISO 2592 | 304 | > 230 |
| Specific gravity | TS EN 15326 | 1.037 | 1.00 to 1.05 |
| Penetration index | EN 12591 | –0.682 | –1.5 to +0.7 |

Class C and F fly ash and hydrated lime were used as filler additives in this study. Hydrated lime which contains 90 % of $Ca(OH)_2$ was used as an antistripping agent of asphalt mixtures. Class C and F fly ashes were obtained from Soma thermic power plant and Catalagzı thermic power plant, respectively. Some physical properties of additives used in this study are given in Table 4. The chemical composition of Class C and F fly ashes is given in Table 5. Class C fly ash is classified as high lime content fly ash according to ASTM C-618. Because content of $SiO_2+Al_2O_3+Fe_2O_3$ is over 50 % (65.01 %) and CaO content is over 10 % (26.50 %). Class F fly ash is classified as low lime content fly ash. Because content of $SiO_2+Al_2O_3+Fe_2O_3$ is above 70 % (89.59 %) and CaO content is less than 10 % (1.48 %).

**Table 4.** Physical characteristics of additional filler materials

| Properties | Fly ash (Class C) | Fly ash (Class F) | Hydrated lime |
|---|---|---|---|
| Spesific gravity, g/cm$^3$ | 2.41 | 2.00 | 2.24 |
| Percent retained (90 μm), % | 33.7 | 21.4 | 4.89 |
| Percent retained (45 μm), % | 52.6 | 38.7 | 15.4 |

**Table 5.** Physical characteristics of bituminous binder (B 50/70)

| Oksit, % | Class C | Class F | ASTM C 618 | |
|---|---|---|---|---|
| | | | Class F | Class C |
| $SiO_2$ | 41.26 | 58.48 | | |
| $Al_2O_3$ | 19.50 | 25.34 | | |
| $Fe_2O_3$ | 4.25 | 5.77 | | |
| $SiO_2+Al_2O_3+Fe_2O_3$ | 65.01 | 89.59 | >70.00 % | >50.00 % |
| CaO | 26.80 | 1.48 | <10.00 % | >10.00 % |
| MgO | 1.82 | 2.22 | | |
| $SO_3$ | 1.10 | 0.12 | <5.00 | <5.00 |
| $K_2O$ | 1.15 | 4.09 | | |
| $Na_2O$ | 0.32 | 0.59 | | |
| KK | 3.05 | 1.01 | <5.00 | <6.00 |
| Cl- | 0.009 | 0.027 | | |

## 2.2. Preparation of specimens

Samples were prepared according to Turkish Highway Technical Specifications. The SMA samples were prepared using a Gyratory compactor according to the SUPERPAVE mixing procedure proposed by NAPA under 100 gyration, 600 kPa pressure and 4.0 % amount of targeted air gap value. The optimum bitumen ratio was determined as 6.5 %. The volumetric specific gravity of compacted samples and the theoretical maximum density of loose asphalt samples were determined according to the AASHTO T166 [28] and AASHTO T209 [29], respectively. Mixture design parameters such as air voids in the compacted mixture (VA), voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) are determined according to test results.

There are generally two methods, wet and dry, for the modification of asphalt mixtures. In the dry method, additives were added by weight of aggregate at percentages of 0.5 %, 1.0 %, 2.0 %, and 4.0 % with replacing stone powder filler in the mixture. In the wet method, the slurry form of additives is mixed with aggregate. First, the slurry was formed mixing water by weight of one third of class C and F fly ash and hydrated lime and then mixed with coarse aggregate. Samples prepared in this manner were dried at 160 °C for 24 hours in the oven. Therefore, samples were prepared at an optimum bitumen ratio of 6.5 % for additives.

## 2.3. Test Methods

### 2.3.1. Indirect tensile test

The strength of asphalt mixtures depends on the tensile strength of bitumen film. An indirect tensile strength test is widely used to determine the behavior of bitumen binding and bitumen matrix under the load. This test is performed using tensile apparatus on Marshall stability test by 50 mm/minute deformation rate and 25 °C temperature. The test was conducted according to ASTM D 6931 standard. A cylindrical sample was placed between the curved loading plates and subjected to load (Fig. 2). Tensile strength ($\sigma_t$) is calculated using maximum breaking load ($P$), sample height ($h$), and sample diameter ($d$).

$$\sigma_t = \frac{2 \cdot P}{\pi \cdot h \cdot d} . \quad (1)$$

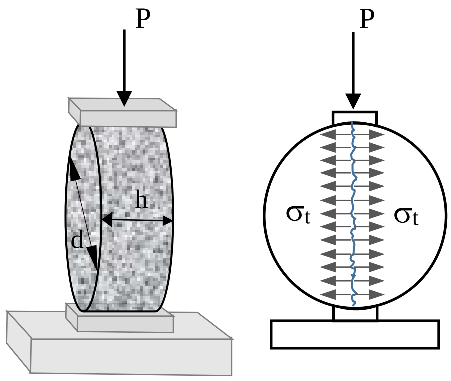


**Fig. 2.** Indirect tensile strength test loading condition

### 2.3.1. Moisture susceptibility test

When the water penetrates the asphalt mixture, it causes damage to the bounds between the aggregates and the asphalt binder, therefore it accelerates the deterioration of pavement [32]. An indirect tensile test is one of the effective methods to determine the effect of water on adhesion between aggregates and bitumen, and the strength of bitumen film. The moisture susceptibility test was performed according to the procedure described in the AASHTO T-283 standard. Modified Lottman test is one of the widely used tests to determine water damage in the asphalt pavement. In this method, the indirect tensile strengths of two groups of compacted samples are determined. The conditional samples were saturated by applying a vacuum for about 5 minutes (Fig. 3) and wrapped tightly in a plastic film layer.

**Fig. 3.** Conditioning stages (vacuuming, freeze-thawing and heating in a water bath) of moisture susceptibility test sample

Then each wrapped sample was placed into a plastic bag containing 10 ml of water. Subsequently, the samples were kept inside a freezing-thawing machine for 16 hours at –18 °C (Fig. 3) and for 24 hours at 60 °C in a water bath (Fig. 3). Finally, the samples were subjected to an indirect tensile test after waiting 2.0 hours at 25 °C in a water bath. Original strength (*TSR*) is calculated using the numerical index of strength ($\sigma_c$) and strength after freezing-thawing ($\sigma_{uc}$) against water.

$$TSR = {}^{\sigma_c}/_{\sigma_{uc}}. \quad (2)$$

## 3. RESULTS AND DISCUSSION

### 3.1. Indirect tensile strength

Additive properties are an important parameter for bitumen film thickness. The dry method is an effective method to prepare mixtures with filler additives. In this section, the effects of filler types, filler amounts, and mixing methods are investigated on the indirect tensile strength of mixtures.

The effects of filler materials added by the dry method on indirect tensile strength can be seen in Fig. 4. The strength of samples prepared by adding class C fly ash with all percentages using the dry method decreases compared to the control specimens. The strength of samples prepared adding class F fly ash is slightly decreased compared to that of control specimens in general. However, 4 % added class F fly ash prepared mixtures increases the strength of samples at about 37 %.

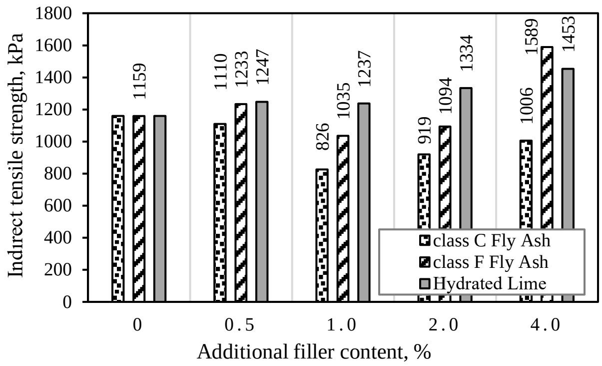


**Fig. 4.** Indirect tensile test results for dry method

However, the strength of samples prepared using hydrated lime is increased with increasing additive amounts. 4 % added hydrated lime prepared mixtures increases the strength of samples by about 25 %. The strength of hydrated lime added samples is regularly increased and the best strength results are obtained using lime added samples. However, the strength of class F fly ash (4 %) prepared mixture is made an important jump. The strength of samples prepared with class C fly ash gives the lowest value among them and is decreased compared to control samples.

Indirect tensile test results of samples prepared using wet method are given in Fig. 5. Strength values of class C added (with all percentages) samples are decreased compared to control specimens. However, the addition of 4 % fly ash (class C) increases the strength of samples. The strength of samples prepared with all percentages of fly ash (class F), except 4 %, using the wet method generally is decreased compared to control samples. The addition of hydrated lime increases the strength of samples.

The best result is obtained by adding 4 % of fly ash (class F) having 33 % increment compared to control specimens. However, the strength of samples prepared with low percentages of fly ash (class F) is decreased compared to control specimens. The strength of 4 % of fly ash (class C) mixed samples is increased by 5.5 % compared to control specimens. The strength of fly ash (class C) added mixtures has the lowest value among the additives and shows decreasing trend compared to control specimens. The addition of class F fly ash to the mixture gives a good result and it is obvious in the case of 4 % added fly ash. This result shows that the optimum filler/binder ratio is obtained and the resulting bitumen film thickness improves the indirect tensile strength. However, the strength of 4 % lime added mixtures is considerably decreased prepared using wet method, unlike dry method.

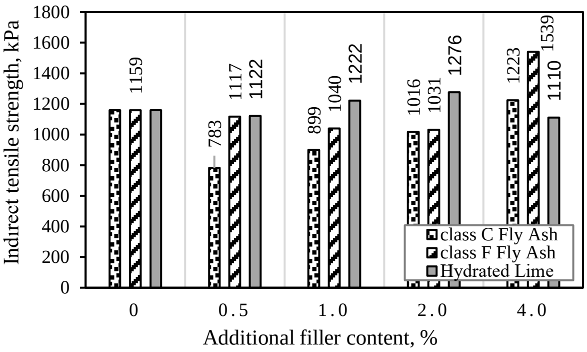


**Fig. 5.** Indirect tensile test results for wet method

The comparison of the indirect tensile strength results obtained in the dry and wet method is presented in Fig. 6. The strength of fly ash (class C) added mixtures is higher than that prepared by using the dry method. The strength increment of samples prepared by using the wet method regularly increases after adding 1 % class C fly ash. The strength results of samples prepared using wet and dry methods are quite close to each other. The strength of samples prepared using the wet method by adding 4 % hydrated lime is considerably decreased compared to that of the dry method.

### 3.2. Moisture susceptibility test

Indirect tensile ratios (ITR) of additives mixed samples prepared using the dry method are given in Fig. 8. ITR values of 1.0 %, 2.0 %, and 4 % fly ash (class C) added samples are improved compared to control specimens. ITR values of additives mixed samples and control specimens are close to each other. However, strength values of 4 % fly ash added samples show considerably low values and drop under the limit value of 80 %. Indirect tensile strength values of lime added samples are regularly decreased. It cannot be seen as an improvement compared to control specimens. Moisture sensitivity values of 2.0 % and 4 % lime added samples stay under the limit values.

Comparing the additives in terms of moisture sensitivity, the ITR values of fly ash (class C) added samples, except 4.0 %, are calculated above 100 % and show important improvement compared to control specimens.

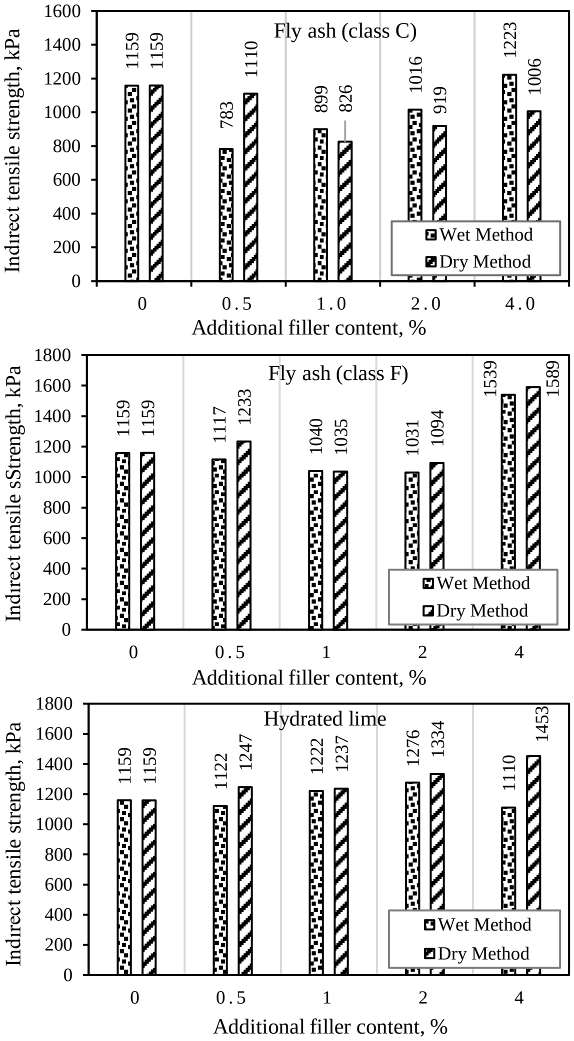


**Fig. 6.** The comparison of the indirect tensile strength results obtained in the dry and wet method

The best result is obtained from 1.0 % fly ash (class C) added sample. While the ITR values of fly ash (class F) added samples show even a little improvement, the ITR values of lime added samples decrease and have the lowest values (Fig. 7).

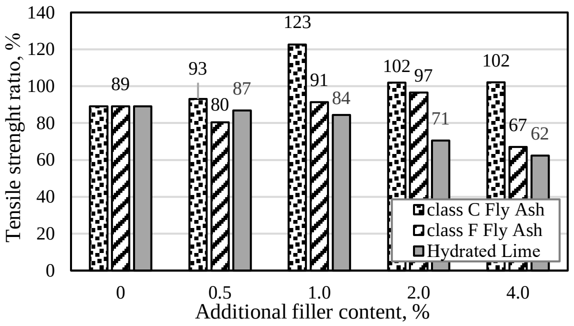


**Fig. 7.** Moisture susceptibility results for dry method

The ITR values of additives mixed samples prepared using the wet method are given in Fig. 8. Samples prepared by adding class C fly ash give better results compared to the other additives. The ITR values of 0.5 %, 1.0 %, and 2 % fly ash (class C) added samples are improved compared to control specimens. ITR values of 4 % fly ash (class C) added specimens stay under the limit value of 80 % (Fig. 8). The ITR values of fly ash (class F) added samples decrease with increasing percent of additives (Fig. 8). ITR values of lime added samples are regularly decreased with an increasing percentage of additives. ITR values of lime added samples stay under that of control specimens. The moisture sensitivity values of 2.0 % and 4.0 % lime added samples stay under the limit value of 80 % (Fig. 8).

When the effects of filler materials on moisture sensitivity of samples prepared using the wet method are investigated, ITR values of fly ash (class C) added samples are better than that of samples prepared using the dry method, except 0.4 % class C fly ash added samples. Class C fly ash added (except 4.0 %) samples show an important improvement.

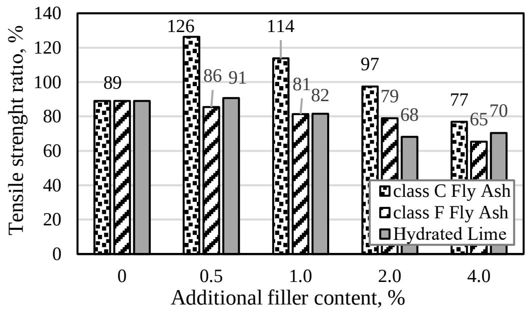


**Fig. 8.** Moisture susceptibility results for wet method

The ITR values of samples are improved by adding 2.0 % class F fly ash. The ITR values of samples prepared using dry and wet methods are close to each other (Fig. 9).

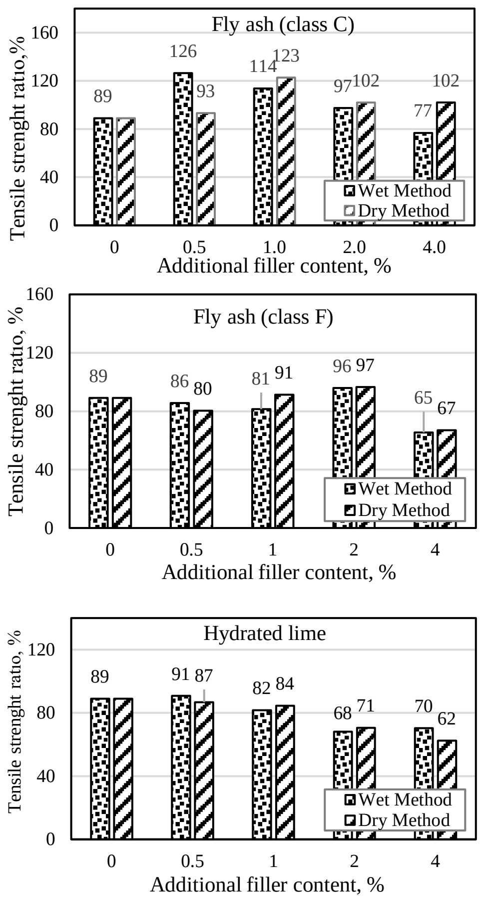


**Fig. 9.** The comparison of the indirect tensile ratio results obtained in the dry and wet method

The ITR values of samples are decreased with increasing percentage of lime, and this is the same for both methods. In general, the effects of mixing methods in the cases of class F fly ash and hydrated lime added samples are not noticeable.

## 3. CONCLUSIONS

The effects of additives such as class C and class F fly ashes and hydrated lime on the strength and moisture sensitivity of asphalt specimens prepared in the laboratory are investigated. Some results and recommendations are given below:

1. Since the diameter of the lime particles is smaller than the other additives and it forms a thin film matrix, the indirect tensile strength values increased with the increase in the addition rate in the dry method. However, the addition of hydrated lime in the wet method partially reduces the indirect tensile strengths. Maximum values are obtained with the addition of 1.0 – 2.0 %. In the wet method. The addition of 4.0 % lime to the asphalt mixture in the wet method is much in the mixture and particles are being agglomerated and adhesion cannot occur and therefore strength is decreased.
2. Indirect tensile test results in the addition of class F fly ash at rates between 0.5 % and 2 % in both dry and wet methods are very close to control samples and each other. However, the addition of 4.0 % class F fly ash significantly improves the strength properties of asphalt mixtures. This result shows that the optimum filler/binder ratio is obtained depending on the grain size of the fly ash and the obtained bitumen film thickness improves the indirect tensile strength.
3. In the wet method, except for the 4 % addition, class C fly ash showed lower indirect tensile strength than the other additives and control samples. Contrary to other additives, the strength values in the wet method are higher than in the dry method. This is due to the high amount of anhydrate lime in class C fly ash.
4. The experimental results show that the moisture strength of class C ash added samples is improved compared to the other additives.
5. ITR values of fly ash (class C) added samples are generally better than that of samples prepared using the dry method.
6. In general, the effects of mixing methods for class F fly ash and hydrated lime are not at a noticeable level.
7. Wet method cannot show expected performance. Practical methods can be investigated to find additives that effectively cover on the aggregate surface.

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