Effect of Fines Content on Dry and Saturated Indirect Tensile Strength of Hot Mix Asphalt Mixtures

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Abstract-Fines and coarse aggregates play vital role in achieving strength properties of hot mix asphalt (HMA) mixtures. ASTM D 3515 recommends nine types of gradations combinations to be used for HMA with variable fractions of fines. In this research the effect of fines in these nine gradations of HMA were evaluated. HMA with variable fines contents were prepared in laboratory using gyratory compactor. The indirect tensile strength using Universal Testing Machine (UTM HYD-25-II) of original and moisture conditioned HMA samples were determined. Tensile strength ratio (TSR) of the HMA samples was also evaluated. It has been observed that with the increase in the fines content the strength and TSR of HMA samples initially increase then it decrease. The HMA mixes having low plastic fines (PI = 6) should not be exceeded beyond 10 % in order to achieve optimum strength.

Keywords-Hot Mix Asphalts, Fines, Indirect Tensile Strength, Tensile Strength Ratio, Moisture Conditioning

I. INTRODUCTION

The design and performance of hot mix asphalt (HMA) is greatly influenced by the nature and amount of the fines in the mix. The properties of fine particles of dense-graded HMA greatly change according to their source. The fines are very important part of HMA and play major role for toughening and stiffening of asphalt binder. The stiffening and toughening effects of fine particles have been documented in detail in the literature. Fine particles are also important for stripping and moisture damage considerations. Fines also play a significant role in HMA mixtures. The high load bearing capacity and strength of HMA is due to aggregate framework developed by intra particles contact and their interlocking. Well graded dense HMA consists of successively different size particles i.e. large particles framework is filled by small particles. The coarse aggregates framework is filled by sand and then mineral fillers. At some stage the small particles loose contact with other particles and becomes suspended in the asphalt binder. These small particles do not have the intra particle contact of larger particles [i]. Detailed studies of the difference between rounded and crushed coarse aggregates in HMA were done in the past by different researchers. The replacement of the rounded aggregates by crushed fine aggregates improved mixture properties increased stability reduced rutting, improved water resistance [ii].

The stripping resistance of asphalt mixtures is evaluated by the decrease in the loss of the indirect tensile strength (ITS) in which cylindrical specimens are subjected to compressive loads. These loads act parallel to the vertical diametric plane by using the Marshall loading equipment. This type of loading produces a relatively uniform tensile stress, which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along with the loaded plane [iii].

Moisture damage is a primaryway of distress in HMA commonly known as stripping. Stripping speeds up structural degradation of the mixtures accompanied by cracking and plastic deformation. The decrease of the adhesion between aggregates and asphalt in the presence of water and the deterioration of the asphalt due to cohesive failure within the asphalt binder itself has been known as two principal driving mechanisms of moisture damage that may results in premature distresses such as raveling and fatigue cracking [iv].

Many highway agencies have been experiencing untimely failures that lessen the performance and servicelife of the pavements.However, the reasons of the increase inpavement distress because of moisture susceptibility havenot been actually identi?ed. Researchers suggest that change of asphalt binders, decrease of asphalt bindercontent to satisfy rutting associated with increase in traffic, change in amount of fines, and poor quality control are the main reasons for increased water sensitivity problems [v-vi].

Maintenance of roads in Pakistan costs annually high percentageof the total road construction costs or in other words, in the future, maintenance cost will become equal to the construction cost of new roads. Roads in Pakistan usually show excessive failures at an early stage of pavement life. The majority of the road network in Pakistan consists of asphalt concrete (AC) pavements. Asphaltic mixtures are composed of bitumen, aggregates, sand and filler particles. In asphaltic pavements, which are continuously exposed to moisture infiltration, separation of the aggregates from the mix is a major problem. The continuous moisture in a pavement induces weakening while traffic load causes the mechanical damage which automatically results in a progressive dislodgement of aggregates. Therefore damaged spots are seen on highways and urban roads, after the seasonal rains, causing strippingdue to the properties of local aggregates (coarse and fine). The existing practices of asphalt mix design technology of Pakistan need up gradation considering local materials, climate and traffic loading conditions existent in Pakistan.The main objective of this research is to evaluate the effect of fines content on dry and moisture conditioned indirect tensile strength of HMA mixtures used in Pakistan.

METHODOLOGY

Following methodology was adopted to achieve the research objectives by consulting references [vii-xiii].

Review of literature to identify most of the gradations used in America, Middle East and Pakistan for the preparation of bituminous mixtures (ASTM D3515) [vii,viii]

Selection of fine aggregates, coarse aggregates and bitumen to be used in HMA mixtures.

Characterization of fine aggregates through specific gravity test (ASTM C 128), grain size distribution test (ASTM D 6913), atterberg limits test (ASTM D4318), sand equivalenttest (ASTM D 2419), sodium sulphate soundness test (ASTM C 88) etc.

Characterization of coarse aggregates through sodium sulphate soundness test (ASTM C 88), Los Angeles abrasion test (ASTM C 131), flaky and elongation test (ASTM D 4791) etc.

Characterization of bitumen through penetration test (ASTM D 5), ductility test (ASTM D 113), flash and fire point test (ASTM D 92), softening point test (ASTM D 36) etc.

Preparation of different HMA mixtures in the laboratory using gyratory compactor (ASTM D 6925) with varying percentage of fines of same physical properties.

Evaluation of indirect tensile strength (ASTM D 6931) of HMA mixtures using servo-hydraulic universal testing machine.

Evaluation of moisture susceptibility of HMA mixtures (ASTM D4867).

Data Analysis include indirect tensile strength and tensile strength ratio calculation

The Indirect tensile strength is computed using equation (1).

$$S_t = \frac{2000*P}{\pi*t*D} \qquad (1)$$

S_t= Indirect Tensile (IDT) strength, kPa
P = Maximum load, N
t = Specimen height, mm
D = Specimen diameter, mm

Tensile strength ratio (TSR) is computed using equation (2)

$$TSR = \left(\frac{S_{tm}}{S_{td}}\right) \qquad (2)$$

TSR = tensile strength ratio
S_{tm}= average tensile strength of the moisture-conditioned sample, kPa
S_{td} = average tensile strength of the dry sample, kPa.

RESULTS AND DISCUSSIONS

Table I presents gradations of bituminous mixtures with respect to the grain size of aggregates and percentage of bitumen, as recommended by ASTM D3515 [vii].

It can be seen from Table I that in different mix designations (D-1 to D-9) fines material (75µm, No. 200) varies from 0 to 20%, cumulative percentage passing. Based on guidelines of ASTM D3515, bituminous mixtures reported inthe parenthesis of Table I are prepared in the laboratory with varying percentage of fines. These mixes are batched by weight.

Gradations D1 to D5 are more capable of taking heavy loads due to more percentage of coarse aggregates. While gradations D6 to D9 are more pronounced for surfacing due to presence to fines as major content.

Ubhanshah aggregate and bitumen obtained from national refinery and attock refinery were used in the preparation of bituminous mixtures. Table II (a) & (b) presents the physical characteristics of fines (sand, silt/clay). The silt/clays are identified as low plastic and sands are identified as medium to fine sands.

TABLE I
COMPOSITION OF BITUMINIOUS MIXTURES AS PER ASTM D3515
(COMPOSITION OF BITUMINIOUS MIXTURES PREPARED IN THE LABORTARY)

Sieve Size	Mix Designation								
	D-1	**D-2**	**D-3**	**D-4**	**D-5**	**D-6**	**D-7**	**D-8**	**D-9**
	Cumulative Percentage Passing %								
63-mm	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)
50-mm	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)
37.5-mm	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)
25.0-mm	60 to 80 (70)	… (…)	90 to 100 (97)	100 (100)	… (…)	… (…)	… (…)	… (…)	… (…)
19.0-mm	… (…)	56 to 80 (70)	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)	… (…)
12.5-mm	35 to 65 (50)	… (…)	56 to 80 (75)	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)	… (…)
9.5-mm	… (…)	… (…)	… (…)	56 to 80 (63)	… (…)	90 to 100 (95)	100 (100)	… (…)	… (…)
4.75-mm (No. 4)	17 to 47 (24 to 27)	23 to 53 (30)	29 to 59 (37)	35 to 65 (42)	44 to 74 (59)	55 to 85 (70 to 71)	80 to 100 (80 to 81)	… (…)	100 (100)
2.36-mm (No. 8)	10 to 36 (20)	15 to 41 (25)	19 to 45 (30)	23 to 49 (30)	28 to 58 (43)	32 to 67 (60)	65 to 100 (67)	… (…)	95 to 100 (95)
1.18-mm (No. 16)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	40 to 80 (65)	… (…)	85 to 100 (85)
600-µm (No. 30)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	25 to 65 (45)	… (…)	70 to 95 (70)
300-µm (No. 50)	3 to 15 (10)	4 to 16 (10)	5 to 17 (15)	5 to 19 (8)	5 to 21 (13)	7 to 23 (20)	7 to 40 (25)	… (…)	45 to 75 (56 to 65)
150-µm (No. 100)	… (…)	… (…)	… (…)	… (…)	… (…)	… (…)	3 to 20 (15)	… (…)	20 to 40 (40)
75-µm (No. 200)	0 to 5 (1 to 3)	0 to 6 (3)	1 to 7 (4)	2 to 8 (5)	2 to 10 (6)	2 to 10 (7 to 8)	2 to 10 (9 to 10)	… (…)	9 to 20 (11 to 20)
Bitumen, Weight % of Total Mixture									
	2 to 7 (4)	3 to 8 (4)	3 to 9 (4)	4 to 10 (4)	4 to 11 (4)	5 to 12 (5)	6 to 12 (6)	7 to 12 (…)	8 to 12 (8)

TABLE II (a)
FINE AGGREGATES (SAND) TEST RESULTS

Sr. No	Tests Description	Results
1	Uncompacted voids [viii]	
	ϒmin (gm / cm3)	1.41
	ϒmax (gm / cm3)	1.64
2	Sand equivalent (%) [ix]	84
3	Specific Gravity [x]	2.68

TABLE II (b)
FINE AGGREGATE (SILT/CLAY) TEST RESULTS

Sr. No	Tests Description	Results
1	Liquid Limit (%) [xi]	22
2	Plasticity Index (%) [xi]	6
3	Clay (%) [xii]	8-10
4	Silt (%) [xii]	90-92

Table III present results of physical characteristics of coarse aggregates. The results show the physical characteristics of *ubhanshah aggregate* falls well within the acceptable typical range of ASTM Specifications.

Table IV shows summary of bitumen physical properties determined from different tests, both samples of bitumen falls well within the typical acceptable range of bitumen samples as recommended by ASTM Specifications.

Aggregates and bitumen were mixed mechanically (ASTM D 6925) and compacted using gyratory compactor (Fig. 1). Table V presents test conditions used during compaction.

One set of the compacted samples was tested using universal testing machine (Fig. 2). Specimens were loaded diametrically, in which cylindrical specimens were subjected to compressive loads. These loads act parallel to the vertical diametric plane. This type of loading produces a relatively uniform tensile stress, which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along with the loaded plane (Fig. 3). Table VI shows test conditions adopted in UTM for determination of indirect tensile strength. This set of samples is designated as "dry" in legends.

Other set of samples was placed in moisture conditioning bath (Fig. 4) for 24 hours at temperature of 60°C ± 1°C as per ASTM D 4867. The temperature of moisture conditioned samples is then adjusted by soaking in a water bath for 1 h at 25 ± 1°C. The elapsed time from removal of test specimen from the water bath to the IDT strength testing using UTM shall not exceed 2 min [xiii]. The conditioned tested samples were designated as "saturated" in legends.

TABLE III
COARSE AGGREGATE TEST RESULTS

Sr. No	Tests Description	Test Results	Specification	Specification Limits
1	Fractured particles (%) [xiv]	100	ASTM D5821	Min. 50, Max 100
2	Flat & Elongated Particles (%) [xv]	7.48	ASTM D4791	Max. 10
3	Resistance to degradation (%) [xvi]	23.86	ASTM C131	Max. 45
4	Durability & soundness (%) [xvii]	0.42	ASTM C88	Max. 10 to 20
5	Water absorption (%) [xviii]	0.44	ASTM C127	-
6	Bulk specific gravity [xviii]	2.68	ASTM C127	-
7	Apparent specific gravity [xviii]	2.71	ASTM C127	-
8	Effective specific gravity [xviii]	2.7	ASTM C127	-
9	Unit weight loose (gm/cm^3)	1.32	-	-
10	Unit weight rodded (gm/cm^3)	1.54	-	-

TABLE IV
BITUMEN PHYSICAL CHARACTERISTICS

Bitumen Source	Tests Description	Test Results	Penetration Grade	Specification	Specification Limits
National Refinery Limited	Penetration Test Result (0.1mm) [xix]	47	40-50	ASTM D5	40-50
	Flash Point (°C) [xx]	335		ASTM D92	Min. 230
	Fire Point (°C) [xx]	372		ASTM D92	Min. 230
	Ductility (cm) [xxi]	121		ASTM D113	Min. 100
	Softening Point (°C) [xxii]	57.1		ASTM D36	Min 48
	Solubility (%) [xxiii]	99.91		ASTM D2042	Min. 99
Attock Refinery Limited	Penetration Test Result (0.1mm) [xix]	67	60-70	ASTM D5	60-70
	Flash Point (°C) [xx]	304		ASTM D92	Min. 230
	Fire Point (°C) [xx]	334		ASTM D92	Min. 230
	Ductility (cm) [xxi]	125		ASTM D113	Min. 100
	Softening Point (°C) [xxii]	48.9		ASTM D36	Min 48
	Solubility (%) [xxiii]	99.86		ASTM D2042	Min. 99

TABLE V
GYRATORY COMACTOR TEST CONDITION [XIV]

Mass of specimen (grams)	2500 to 2700	ASTM D6925
Vertical Pressure (kPa)	600 ± 18	ASTM D6925
Number of revolutions	205	ASTM D6925

TABLE VI
UTM TEST CONDITIONS [XXV]

Sample thickness (mm)	50.8	ASTM D6931
Sample diameter (mm)	101.6	ASTM D6931
Test temperature (°C)	25	ASTM D6931
Deformation rate (mm/min)	50 ± 5	ASTM D6931

Fig. 1. Gyratory Compactor Setup

Fig. 2. Servo Hydraulic Universal Testing Machine

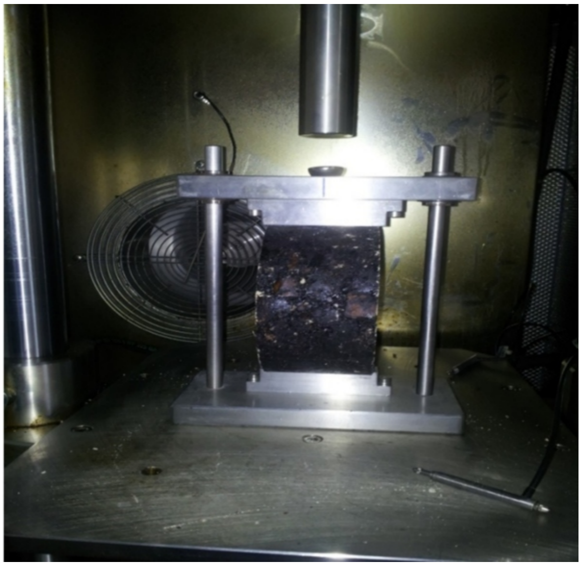

Fig. 3. Specimen Testing Machine

Fig. 5 show comparison of dry and saturated indirect tensile strength (ITS) with respect to percentage of fines (sand, silt/clay) in HMA mixtures prepared using penetration grade 40-50.

In Fig. 5, it can be seen that for dry samples indirect tensile strength of 1300kPa is obtained with 24% of sand and 1% of silt/clay in HMA mixture, which increases up to 2000kPa with 50% sand and 10% silt/clay after which it decrease. From above results it can be concluded that initial increase in IDT strength with increasing sand or silt/clay percentage is due to the mixes containing successively smaller particles such that the framework created by the larger particles is just filled by the smaller particles. Thus the coarse aggregate framework is filled by the sand-sized material and finally by the silt or clay resulting in a dense HMA mix, that is why maximum strength is also achieved with 50% sand and 10% silt/clay in the mix. After decreasing to 1000kPa the indirect tensile strength almost becomes constant above 70% sand and 17% silt/clay in the HMA mix [xxvi]. Hence increase in any further amount of fines does not affect the indirect tensile strength of the HMA mixes. For saturated samples the indirect tensile strength obtained is lesser as compared to that of dry samples but overall trend remains the same. Saturated strength is lesser as compared to dry strength, due to the loss of adhesion (stripping) or loss of cohesion (i.e. softening of asphalt that weakens the bond between asphalt and aggregate) due to the intrusion of water into the HMA mix. The stripping of asphalt from the aggregates results in the reduction of strength of asphalt concrete mixture [xxvii].

Fig. 4. Moisture Conditioning Bath

Fig. 5 also shows variation of tensile strength ratio (TSR) by the addition of fines (sand, silt/clay) using penetration grade 40-50. In Fig. 5 it can be clearly observed that tensile strength ratio of 0.80 is achieved for 24% of sand and 1% of silt/clay and then there is an increase in TSR with increasing percentage of sand in the mix up to 0.92 at 50% sand and 10% silt/clay after which the TSR shows a decreasing trend. TSR is used for predicting the moisture susceptibility of the mixtures. According to previous researches a TSR of 0.8 or above has typically been utilized as a minimum acceptable value for hot mix asphalt. Mixtures with tensile strength ratios less than 0.8 are moisture susceptible and mixtures with ratios greater than 0.8 are relatively resistant to moisture damage [xxviii, xxix]. After moisture conditioning approximately 20% reduction in strength is observed at 24% of sand and 1% of silt/clay in HMA mix which improves to 7% at 50% of sand and 10% silt/clay in HMA mix. Since the aggregates formwork is strongly interlocked with coarse and fine aggregates, it is difficult for moisture to percolate through the mix. The reduction in strength exceeds 25% at 70% sand and 17% silt/clayin the HMA mix because there is no stronger aggregate-bitumen bond due to presence of larger amount of fines in HMA mix [xxx].

Fig. 6 show comparison of dry and saturated indirect tensile strength with respect to percentage of fines (sand, silt/clay) in HMA mixtures prepared using penetration grade 60-70. In Fig. 6 it can be seen that for dry samples initial indirect tensile strength at 24% of sand and 1% of silt/clay in HMA mix is near 900kPa, which is lesser as compared to indirect tensile strength obtained using penetration grade 40-50 as in Fig. 5. Since 40-50 is harder grade as compared to 60-70 therefore its strength is also relatively higher as compared to 60-70 which is softer grade. Indirect tensile strength increases up to 1400kPa for 50% of sand and 10% silt/clay in HMA mix after which it decreases to 900kPa at 70% sand and 17% silt/clay in the HMA mix. For saturated samples the indirect tensile strength obtained is lesser as compared to that of dry samples but overall trend remains the same.

Fig. 6 also shows variation of tensile strength ratio (TSR) by the addition of fines (sand, silt/clay) using penetration grade 60-70. In Fig. 6 it can be clearly observed that tensile strength ratio of 0.78 is achieved for 24% of sand and 1% of silt/clay and then there is an increase in TSR with increasing percentage of sand in the mix up to 0.92 at 50% sand and 10% silt/clay after which the TSR shows a decreasing trend. After moisture conditioning approximately 23% reduction in strength is observed at 24% of sand and 1% of silt/clay in HMA mix which improves to 8% at 50% of sand and 10% silt/clay in HMA mix. Since the aggregates formwork is strongly interlocked with coarse and fine aggregates, it is difficult for moisture to percolate through the mix. The reduction in strength exceeds 23% at 70% sand and 17% silt/clay in the HMA mix because there is no stronger aggregate-bitumen bond due to presence of larger amount of fines in HMA mix.

CONCLUSIONS

Following conclusions can be drawn from the findings of the research:

1. Bitumen penetration grade 40-50 shows more indirect tensile strength than grade 60-70 for all evaluated HMA mixes tested in original as well as moisture conditioning condition.
2. For penetration grade 40-50
   a. The indirect tensile strength of HMA gradations (D1 to D9) is 1300kPa at 25% fines (sand, silt/clay) in the mix which increase up to a limit of 2000kPa with 60% fines content then it shows decrease.

   For Penetration Grade 60-70

   b. The indirect tensile strength of HMA gradations (D1 to D9) is 900kPa at 25% fines (sand, silt/clay) in the mix which increase up to a limit of 1400kPa with 60% fines content then it shows decrease.
3. All evaluated HMA mixes showed good resistance to moisture susceptibility therefore TSR of all the nine ASTM D 3515 gradations (D1 to D9) typically range less than 1. Same has been reported in the literature also.
4. The silt/clay of low plastic characteristics (up to PI = 6) should not be used more than 10% in the HMA mixes D1 to D5 to ascertain optimum strength under heavy traffic loading.

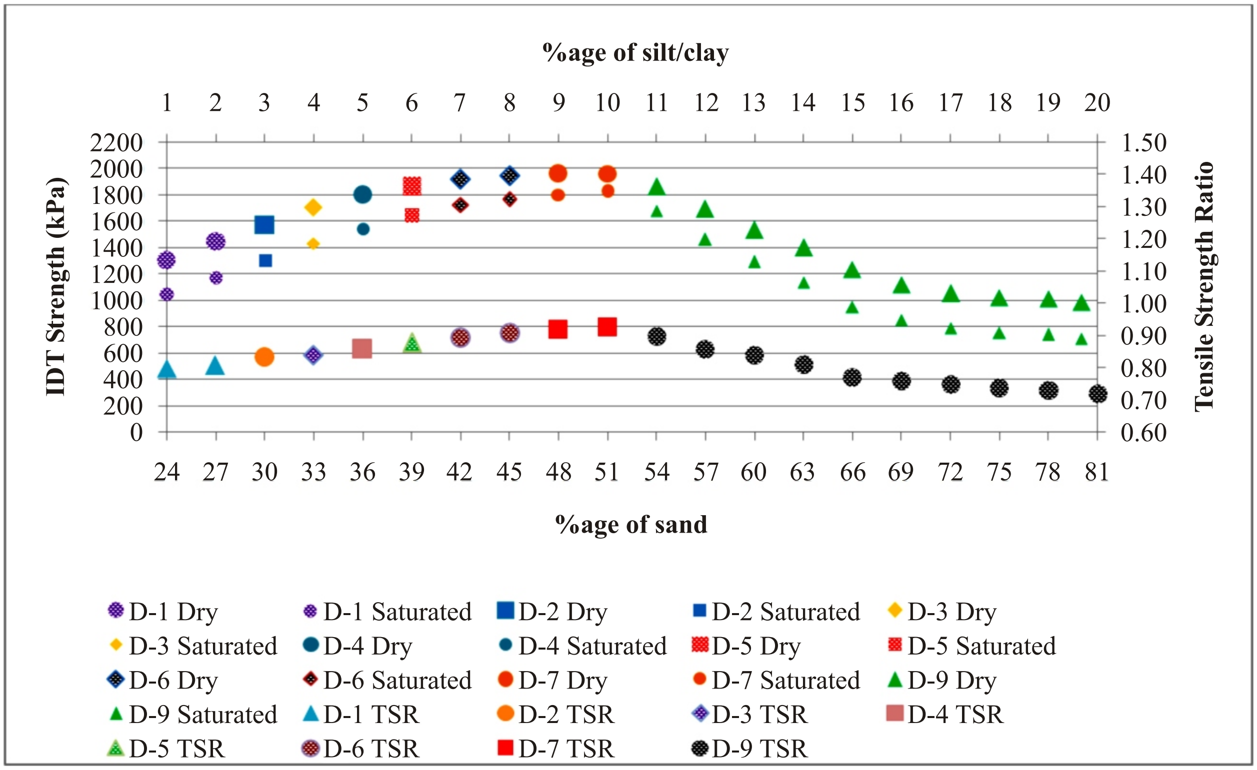

Fig. 5. ITS and TSR vs. % Fines Content (Penetration Grade 40-50)

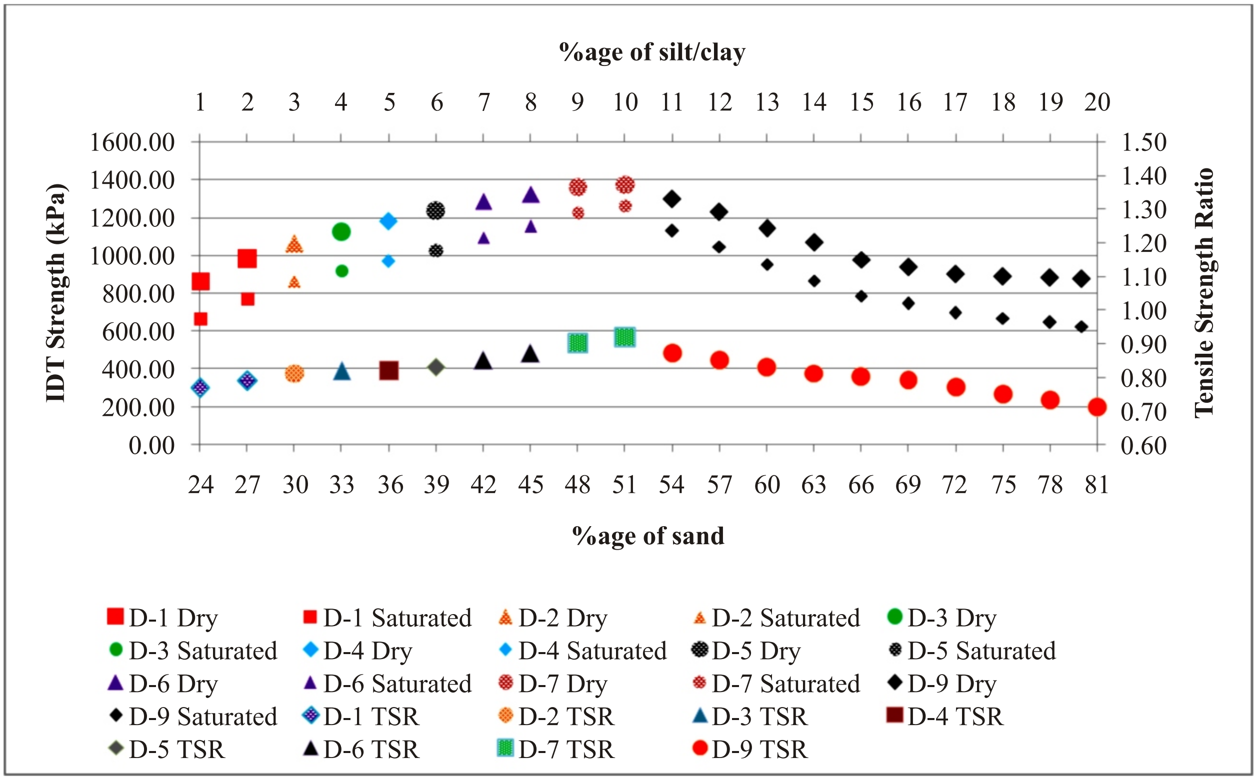

Fig. 6. ITS and TSR vs. % Fines Content (Penetration Grade 60-70)

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