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Rutting performance of polypropylene modified asphalt concrete

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Abstract

Rutting in asphalt concrete is a very common form of distress in asphalt concrete pavement which unfortunately has been incurable to date. One of the prime reasons of rutting is attributed to the behaviour of asphalt binder at elevated temperature. This study has investigated the performance of polypropylene fibres modified asphalt concrete mix against rutting. Two types of asphalt concrete samples were prepared namely control samples (those without polypropylene addition) and modified samples (with polypropylene modification). Marshall Mix Design was used for determining the Optimum Asphalt Content for both sample types. Slab asphalt concrete specimens of dimensions 300 mm length and breadth and 50 mm thickness were prepared for both control and modified samples. These samples were then tested in the Wheel Tracking Device for rutting susceptibility test. The samples were tested at four temperatures i.e. 40°C, 50°C, 55°C and 60°C and under the application of 10 000 load passes of 700N of axle load.. The polypropylene fibres were found to increase the Marshall Stability by almost 25%. The fibres were also determined to be effective against rutting at elevated temperatures while the modification was found to increase the Indirect Tensile strength by stiffening the mix at high temperature however at low temperature, the modification failed to perform effectively.

Keywords: *Polypropylene fibres, Marshall stability, Rutting susceptibility, Rut resistance, Indirect tensile strength wet method, Asphalt modification, Monofilament fibre.*

1. Introduction

In Pakistan, the roadways are usually made as flexible due to their low cost as compared to the rigid pavements. Flexible pavement experiences traffic loading and environmental factors (rain fall and temperature) that affect the performance of pavement and creates various distresses. Majority of the roads in Pakistan are in poor condition owing to these distresses. According to National Highway Authority (NHA), 67% of their road network is in poor condition with rutting being the most common form of roads distresses. The distresses like rutting and fatigue cracking have degraded the condition of the available road network making them unsafe and dangerous for the road users simultaneously affecting the country’s economy. Currently Pakistan has almost 260, 000 km of road network which is widely used and carries 91% passenger traffic and almost 96% of the freight traffic [1,2]. Unfortunately, the gap between the funds required and available for maintenance and rehabilitation activities has never been bridged since 1999-2000 [1].

In this scenario it is crucial to research for materials that could be incorporated in pavements for making them durable and more resistant to distresses. Such pavements will have greater service life than the conventional pavements and will, therefore, require lesser maintenance.

One method of making durable pavements is by polymer fibre modification. It is considered as one of the solution to improve fatigue life, reduce rutting and thermal cracking in the pavement [3]. In this project the option of incorporating polypropylene fibres in asphalt concrete pavement is investigated by keeping rutting as the main distress. Marshall Stability is a vital parameter widely employed for mix design and quality control checks [4]. Conclusively, it can be said that this study presents the laboratory evaluation of using polypropylene fibres in pavement. Polypropylene fibres have been in similar use for quite some time now. These fibres have been particularly used for the purpose of controlling the permanent deformation, rutting [5,6]. Also the pavements have been found to be more durable and have greater service-life after polymer modification because the polymer addition was found to improve the ductility of the binder [7].

Marshall testing has shown increased stability and flow values by addition of polypropylene fibres. Ebrahimi [8] prepared asphalt specimens by Superpave Gyratory Compactor (SGC). These samples were analysed by both Marshall Analysis and Superpave Analysis and finally

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tested by Marshall Stability. It was observed that adding PP showed increasing in Marshall Stability (26.3%), percent of air void (67.5%), and also decreasing Flow (38%). These results show increase pavement life service, also increasing percentage air void is useful for hot regions which bleeding and flushing are important distresses.

Tapkin et al. [9] performed repeated creep tests and concluded the addition of the polypropylene fibres into the asphalt mixture increased the Marshall Stability value by 20%. It can be concluded that the lives of the fibre modified asphalt specimens under repeated creep loading at different loading patterns increased by 5–12 times versus control specimens. This is a significant improvement. The results from the analysis of the tested specimens show that the addition of polypropylene fibres improves the behaviour of the specimens by increasing the life of samples under repeated creep testing.

Simpson and Kamyar [10] conducted another study in which polypropylene, polyester fibres, and some other polymers were used to modify the bituminous binder. The testing procedures included Marshall Stability, Indirect Tensile Test, moisture damage susceptibility, freeze/thaw susceptibility, resilient modulus, and repeated load deformation. Mixtures containing polypropylene fibres were found to have higher tensile strengths and resistance to cracking. Rutting potential as measured by repeated load deformation testing was found to decrease only in polypropylene modified samples.

Hence the superiority of using polypropylene over the conventional methods was established in this research.

From the literature it can be concluded that the propylene mixed asphalt concrete is behaving well under different testing conditions. A number of researchers found the propylene modified asphalt concrete rut resistant at various loadings but responses at different temperature regime is missing. Therefore based on the studied literature, the following objectives for this study were derived.

i) Determine the effect on Marshall Stability because of the inclusion of polypropylene fibres in the asphalt concrete.

ii) Evaluate the effectiveness of polypropylene fibres against mix-rutting in Hot Mix Asphalt (HMA) samples.

iii) Determine the resilient modulus of polymer modified samples using Indirect Tensile strength test(IDT)

The scope of this study includes investigation of Optimum Asphalt Content (OAC) by Marshall Method using 11 lb/ton (0.5% by weight of aggregates) of polypropylene fibres addition [11]. The Marshall Stability values at each level of addition of asphalt binder were noted for both the control and modified samples. The levels of addition of asphalt used in this research for Marshall Mix Design included 3.5%, 4.0%, 4.5%, 5.0% and 5.5%. The OAC was then used in the preparation of samples for rutting tests. Twenty four (24) HMA samples each of 2 inch (50mm) thickness were prepared for and tested at 40°C, 50°C, 55°C and 60°C respectively against rut resistance. The rutting susceptibility testing was done using the Wheel Tracking Device. The scope of the rutting test was limited only to the investigation of mix rutting. Based on the results of the laboratory testing of this study, effectiveness of polypropylene fibres in increasing the rut resistance of HMA had been determined. Another limitation in this study was the axle load and maximum temperature (700 N and 60°C which is the limitation of Wheel Tracking Device available at the premises. The results of this study are expected to, but not guaranteed, to perform satisfactorily under greater axle load. Moreover the effect of 13 mm monofilament polypropylene fibre had been investigated only, ignoring the other types and lengths of polypropylene fibres. The scope of this study also included investigation of resilient modulus of polypropylene modified asphalt concrete by IDT . The samples, control and modified, had been prepared using the Optimum Asphalt Content determined earlier and cylindrical samples of 2.5 inch thickness and 4 inch height were casted accordingly. The samples were tested for IDT at two test temperatures i.e. 40°C and 60°C only.

2. Experimental Program

This section discusses the details of the materials used and the different tests employed. The aggregate gradation employed in this research is *NHA Type A (Minimum)(It is Identical to ASTM 136-05)* whose gradation curve is shown in Fig. 1.

Monofilament polypropylene fibre has been used in this research as shown in Fig. 2 and its properties are given in Table 1.

Table 1 Properties of Polypropylene fibres used in this study [12]

Characteristic	Value	Standard
Colour	Transparent	
Length (mm)	13	
Compressive strength (psi)	5,500-8,000	ASTM D695
Flexural strength (psi)	6,000-8,000	ASTM D790
Tensile strength at break (psi)	4,500-6,000	ASTM D638
Elongation at break (%)	100-600	ASTM D-638
Water Absorption (%)	Negligible (0.01-0.03)	ASTM D-570
Specific Gravity	0.9-0.91	ASTM D-792
Ignition Point	593°C	ASTM D-4101

Melting Point	160 – 170°C	ASTM D-1238
Heat and UV Stabilization	Long term	ASTM D- 4329
Thermal conductivity	2.810^{-4} cal cm/sec cm	ASTM D- 5390
Tensile modulus (ksi)	165-225	ASTM D-638
Compressive modulus (ksi)	150-300	ASTM D-695
Flexural Modulus (ksi @ 25°C)	170-250	ASTM D790

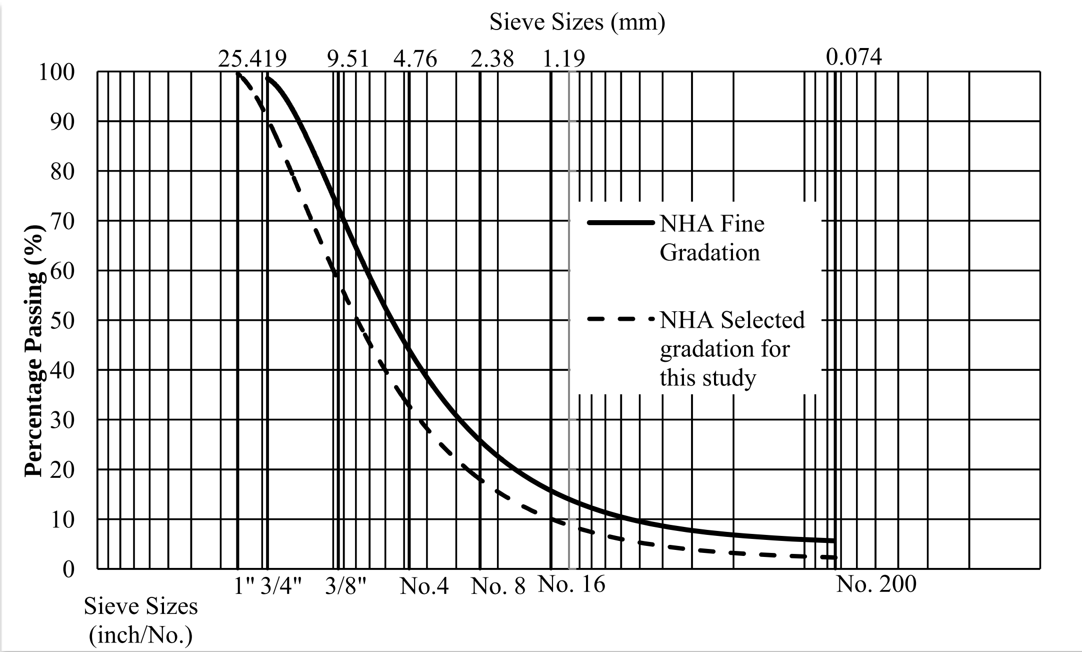

Fig. 1 Aggregate gradation curve

Fig. 2 Polypropylene fibres taken in containers

2.1. Addition of polypropylene fibre to asphalt

For preparing asphalt concrete samples, 60/70 penetration grade asphalt was used. In order to add polypropylene in a mix a technique called "*Wet Method"* [11] has been adopted in this research. The required quantity of fibre i.e. 5 kg/ton (0.5% by weight of mix) was first taken in the pan and then heated asphalt (150°C) was added and mixed thoroughly until the mix acquires uniformity. This method is well illustrated in Fig. 3.

Fig. 3 Mixing asphalt binder and fibres

2.2. Preparation of mix

Once the asphalt propylene mixture was obtained then it was added with aggregates and the mix was thoroughly mixed until each aggregate particle was adequately coated with mixture. The prepared mix was further kept in oven at 120°C for four (4) hours for aging of the mix. The samples were later compacted in a cylindrical mould of 4 inch diameter, by application of 75 hammer blows on each side.

2.3. Marshall Stability Test

The OAC of control as well as modified samples has been determined using the Marshall Mix Design Method. After determining the OAC samples for rutting tests were prepared. Density at OAC from Marshall Tests was used to calculate the mass of aggregates required for rutting tests for both control and modified samples. Marshall Stability values for both types of samples were obtained by testing the samples in Marshall Testing Machine.

2.4. Rutting susceptibility test

The mixing of sample for rutting tests were done identically in the same manner as it was for Marshal test (ASTM D 1559); however, the samples were compacted in Roller Compactor. Twelve samples each of control and polypropylene modified samples were thus prepared.

After compaction, the samples were tested in Wheel Tracking Device. Three control and three polymer modified samples each were tested at 40°C, 50°C, 55°C and 60°C respectively. Average rut depth values were calculated for both control and modified samples. The average rut depth values of control samples were compared with the average rut depth values of polymer modified samples to ascertain the effectiveness of polymer modification.

2.5. Indirect tensile test

The IDT was carried out for determining the Modulus of Resilience (M_R) of the control and polymer modified samples. The tests were carried out at two temperatures, same as those for rutting tests, i.e. 40°C and 60°C. The samples tested in this test were cylindrical samples of length 50mm and diameter 100 mm. The test was conducted at test pulse period of 1000ms, condition pulse period of 2000ms and condition pulse count of 5 at maximum load of 100N and 300N. Two samples each of control and Polypropylene modified samples were tested at each temperature. At each temperature, one control sample was tested by application of 100N peak load while the other sample was tested by applying 300N load. Similar methodology was used for testing Polypropylene modified samples. Therefore a total of eight samples were to be tested in Indirect Tensile Test. However the control sample could only be checked under 100N load application at 60°C because, at elevated temperature, the sample was quite soft and made it impossible to place the Linear Variable Displacement Transducer (LVDT).

3. Results and Discussion

This section describes the result obtained by the different tests mentioned in the previous section as well as analysis of those results in detail.

3.1. Marshall stability result

The OAC was determined to be 5% for the control samples and 5.5% for the polymer modified samples. The results of the Marshall Stability tests are given in Fig. 4 and Fig. 5. It can be seen from both the figures that at all levels of addition of asphalt binder, the Marshall Stability values of modified samples is greater than that of control samples.

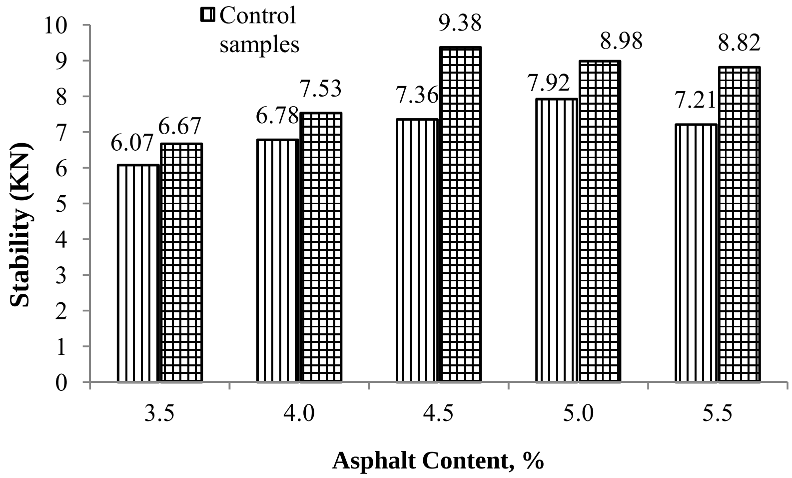

Fig. 4 Marshall Stability of control and modified samples

From Fig. 5, it can be seen that the trend followed by both the control and modified samples is quite logical. The experimental results are also perfectly aligned with the reviews literature. The stability values of control and modified samples are increasing with the increase in percentage level of addition of asphalt binder initially. The stability values start decreasing after reaching the maximum. The maximum stability value for the control samples was found to be approximately 7.562 KN while for the modified samples the maximum stability was recorded around 9.341 KN. At OAC i.e. at 5% asphalt content for control samples, the stability value is coincidentally the maximum value recorded for the control samples. In the case of modified samples, the stability value at OAC i.e. 5.5% was found to be 8.8807 KN approximately.

From both Fig. 4 and Fig. 5 it can be seen that at all levels of percentage asphalt content the Marshall Stability of the modified samples is greater than the control samples. The polypropylene modification has been found to increase the stability by almost 25%. All the stability values of modified samples are almost 25% greater than the control samples. It is evident that polypropylene modification has increased the stability of the asphalt concrete samples quite effectively.

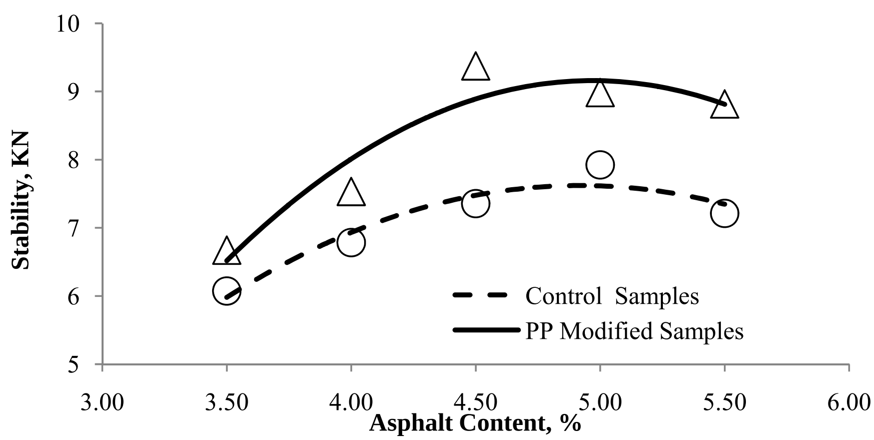

Fig. 5 Trend of Marshall Stability Values of control and modified samples

3.2. Rutting tests results

The rutting tests were carried out at three test temperatures of 40°C, 50°C, 55°C and 60°C. As mentioned earlier three samples each, control and modified, were tested at the mentioned test temperatures. Fig. 6 shows the final average rut depth of control and modified samples, respectively, at various passes and afore-mentioned test temperatures. The aim of this study was twofold: firstly to investigate the effectiveness of Polypropylene modification and secondly to understand the effect of increase in temperature on rut depth while keeping the level of addition of Polypropylene fibres constant.

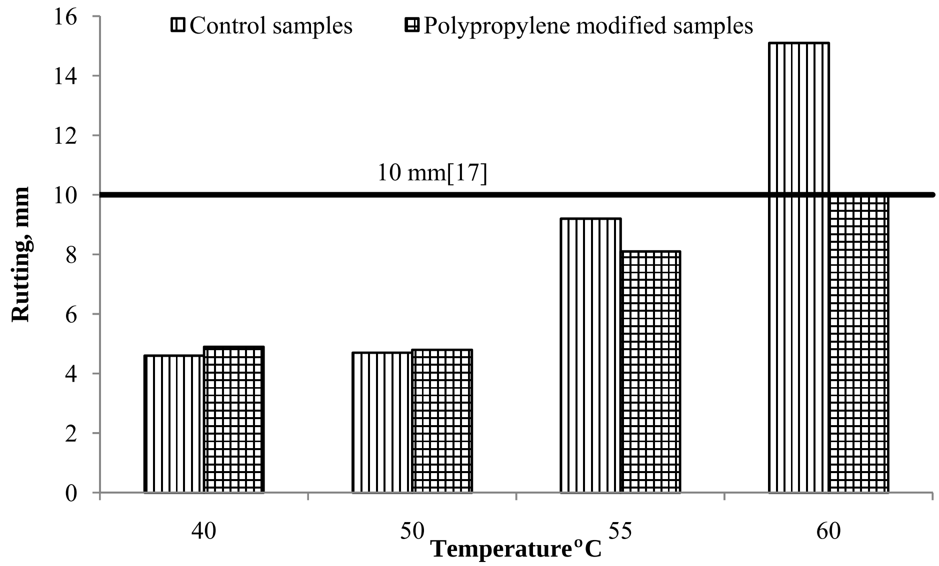

Fig. 6 Average final rut depths of control and modified samples

The effect of increase in temperature over the rutting susceptibility of both control and polypropylene modified samples can be studied from Fig. 6. The final average rut depth after 10 000 passes is found to be increasing with the increase in test temperature in the case of control samples. While for the modified samples, the final average rut depth of modified samples tested at 40°C and at 50°C was greater than its counterpart control sample. However for other two test temperatures, i.e. 55°C and 60°C, the final average rut depth of modified samples is less than their counterpart control samples.

From Fig. 6, it can be seen that Polypropylene modification has been rendered useless at test temperature of 40°C and at 50°C. The final rut depth of control samples is lesser than the modified samples at 40°C and at 50°C. The probable reason for this behaviour being that inclusion of fibres in the asphalt mix increases the air void content thus increasing the permanent deformation i.e. rut depth as compared to the control samples. The increase in air voids content by inclusion of fibres has also been reported by Tapkin [13]. Therefore, at temperature of 40°C the Polypropylene fibres not only failed to increase the rut resistance of asphalt concrete but increased the air void contents which led to greater rut depth.

The effectiveness of Polypropylene modification is clearly evident at test temperature of 60°C. The modification has reduced the rut depth from 15.1mm to 10mm i.e. reducing the rut depth by about 51%. This is a significant reduction in rutting by Polypropylene modification. The reason for this being that initially the polymer modified samples had more air void content than control samples [13], the binder had softened at elevated temperature of 60°C, however, the Polypropylene fibres added strength and reinforcement to the mix. Therefore, it can be conclusively concluded that the Polypropylene modified asphalt concrete is efficient in curtailing rutting at elevated temperatures i.e. above 50°C. At lower temperatures, the modification is found to be useless for restraining rutting.

Furthermore, the maximum rut depth allowed by the Asphalt Institute is 10 mm which is also shown in Fig. 6. It can be clearly seen that the rut depth of the control sample at the elevated temperature of 60°C is crossing this threshold rut depth criteria set by Asphalt Institute. The modified samples have shown an average rut depth just equal to the maximum rut depth i.e. 10 mm. Hence, it can be said that Polypropylene modification has reduced and curtailed the final average rut depth just under the threshold limit.

Fwa [14] has reported the classification of the rut depth and their corresponding severity levels as follows:

1. For rut depth less than 6mm the severity level is *low* and problems of hydroplaning and wet-weather accidents are not likely to occur,
2. for rut depth between 7 and 12 mm the severity level is *medium* and problems of hydroplaning and wet-weather accidents are probable while
3. for rut depth greater than 13 mm the severity level is *high* and potential for hydroplaning and wet-weather accidents are greatly increased.

Based on this model we can classify the rut depths of control and polymer modified samples to their severity levels. The average rut depths of the samples after 10 000 load passes have been used for making this classification. The classification is given in Table 2.

Table 2 Rut depths of control and modified samples and their associated severity levels

Sample Type	Temperature (°C)	Rut Depth (mm)	Severity Level [14]
Control samples	40	4.6	Low
Polypropylene modified samples	40	4.9	Low
Control samples	50	4.9	Low
Polypropylene modified samples	50	5.1	Low
Control samples	55	9.2	Medium
Polypropylene modified samples	55	8.1	Medium
Control samples	60	15.1	High
Polypropylene modified samples	60	10	Medium

From Table 2, it can be observed that Polypropylene modification 40°C and 50°C has not brought about any change in severity level as compared to the control samples. However, polymer modification has reduced the severity level from high to medium at 60°C. Concluding it can be said that Polypropylene modification is effective can reduce the severity level associated with rut depth from high to medium at 60°C.

3.3. Indirect tensile test

The Indirect Tensile test was carried out on both control and samples prepared with Polypropylene modification. The samples were tested at the two test temperatures i.e. 40°C and 60°C. The other details of Indirect Tensile Test are given in preceding section. The results of the tests are illustrated below in Fig. 7.

Fig. 7 shows the values of Modulus of Resilience (MR) of control and modified samples at 40°C and 60°C. It can be seen that at 40°C the value of MR of control samples is greater than the value of MR of polymer modified samples at the same temperature. The resilient modulus decreased slightly (almost 15%) by polymer modification at test temperature of 40°C. For test temperature of 60°C the modulus of resilience of polypropylene samples is found to be greater than that of control samples. Resilient modulus increased by almost 2.8 times with Polypropylene modification at 60°C (380/135.4=2.8).

Fig. 8 shows the temperature and IDT strength of control and modified samples. As discussed earlier the IDT strength of control and modified samples both was found to be decreasing with the increase in temperature. Initially at 40°C the IDT strength of the control samples was greater than that of modified samples. However, with the increase in temperature, the IDT strength of both samples decreased. At 60°C the IDT strength of modified samples was found to be greater than control samples' IDT strength. Again from Fig. 8, it can be seen that at temperature of around 47.7°C, the IDT strength of control and modified samples is same, i.e. 760 MPa. In a manner, the temperature of around 48°C can be considered as the threshold temperature i.e. the polypropylene modification should be considered for increasing IDT strength in scenarios where the asphalt concrete temperature is mostly above 48°C.

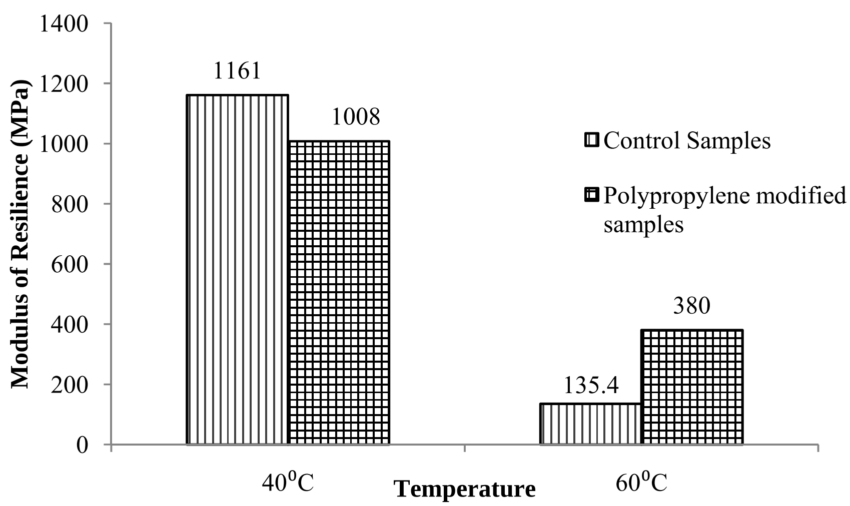

Fig. 7 Resilient Modulus of control and modified samples

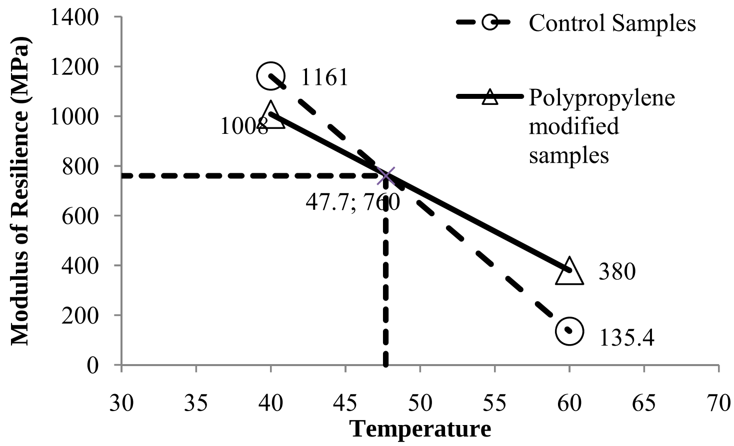

Fig. 8 Temperature and IDT strength correlation for control and modified samples

Fig. 8 shows the temperature and IDT strength of control and modified samples. As discussed earlier the IDT strength of control and modified samples both was found to be decreasing with the increase in temperature. Initially at 40°C the IDT strength of the control samples was greater than that of modified samples. However, with the increase in temperature, the IDT strength of both samples decreased. At 60°C the IDT strength of modified samples was found to be greater than control samples' IDT strength. Again from Fig.8, it can be seen that at temperature of around 47.7°C, the IDT strength of control and modified samples is same, i.e. 760 MPa. In a manner, the temperature of around 48°C can be considered as the threshold temperature i.e. the polypropylene modification should be considered for increasing IDT strength in scenarios where the asphalt concrete temperature is mostly above 48°C.

Zaniewski and Sirinivasan [15] has reported the findings of Christenson et al., 2000 [16] regarding the correlation between Indirect Tensile Strength (IDT) and the rutting resistance of the mix. It was discussed that IDT strength can be used as a parameter for ascertaining the rut resistance of asphalt concrete as shown in Table 3.

Table 3 Guidelines for Evaluating Rut Resistance Using IDT Strength [12]

RSCH MPSS, %	IDT Strength (kPa)	Rut Resistance
< 1.0	> 440	Excellent
1.0 to < 2.0	>320 to 440	Good
2.0 to < 3.0	>200 to 320	Fair
≥ 3.0	≤ 200	Poor

The guideline shown above can be used in this research for validating the results of the rutting tests carried out. At 40°C, the value of IDT strength of control and modified samples is greater than 440 MPa and hence both mixes have excellent rut resistance. However at 60°C, the IDT strength of modified sample being greater than 320 MPa and less than 440 MPa has good rut resistance. While for control samples the IDT strength being less than 200 MPa, it has rut the poor rut resistance. The rut depth of modified samples at 60°C was lesser than the rut depth of control samples which is perfectly in accordance with the above mentioned guidelines [17].

The results of the rutting susceptibility tests discussed earlier can be validated by the results of Indirect Tensile tests. From Fig. 6 it can be learned that the rut depth of polypropylene modified samples is greater than the rut depth of control samples at 40°C, similar is the case in IDT. The modulus of resilience of polypropylene modified samples at 40°C is lesser than the resilient modulus of control samples at the same temperature. The control samples, possessing greater resilient modulus than modified samples, exhibited lesser degree of permanent deformation than the modified samples. While for the case of test temperature of 60°C, the resilient modulus of polypropylene modified samples was found to be greater than the resilient modulus of control samples as shown in Fig. 6. Thus, the control samples showed more permanent deformation, i.e. rutting, than the modified samples.

3.4. Life cycle cost analysis (LCCA)

The LCCA was performed using Darwin 3.1(AASHTO WARE 1993). The resilient modulus (MR) values for control and modified asphalt concrete were obtained from the indirect tensile strength test. From LCCA the life cycle cost of pavement section using control or conventional asphalt concrete was determined to be Rs. 19,725,857(US $ 197,246) while for modified concrete was found to be Rs. 22,075,087 (US $ 220,737). For LCCA, the maintenance cost was arbitrarily assumed to be Rs. 50,000(US $ 499). The analysis was performed for a two lane two direction one mile road length, so it can be said that the cost of polypropylene modified asphalt concrete pavement is around 18% greater than the life cycle cost pavement using control asphalt concrete. However the rut depth was found to decrease approximately by 51% because of Polypropylene inclusion. Therefore, it can be safely assumed that maintenance required for modified asphalt concrete section would be lesser than that of control or conventional asphalt section at elevated temperature. Since Polypropylene modification has behaved so extraordinarily in increasing the rut resistance of HMA at elevated temperature, the modification is expected to increase resistances against other common distresses as well. In this way, by spending marginally more cost than that spent for conventional HMA (around 18% more), a more durable pavement could be constructed.

4. Conclusion

The results of the experimental work and analysis carried out in this research project will be discussed in this section. The following conclusions can be made based on the results of this research:

1) The rut depth is found to increase with increase in test temperature for the control samples. The increase in temperature was found to decrease the rut resistance of the control samples

2) Polypropylene fibre modification has been found to increase the rut resistant of asphalt concrete only at elevated temperatures.

3) At low temperatures, say 40°C, the polymer modification has been found to be ineffective in increasing rut resistance of HMA.

4) Polypropylene fibre performed very effectively in resisting the rut formation at elevated temperatures, say 60°C.

5) The polypropylene modification has been found to increase the resilient modulus and, consequently, the elastic modulus of asphalt concrete at elevated temperatures.

It is to be noted that though the conclusion drawn in this study are already known but the author contribution can be attributed from the following reasons:

- Behaviour of polypropylene at different temperature regime suggesting that use of polypropylene is not beneficial at cold regions especially where the pavement temperature is below 50°C.

Experimentation with Polypropylene fibres in asphalt concrete, first time in Pakistan

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