Effect of the Polypropylene Fibre as Replacement of Filler on Asphallic Concrete Performance

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Abstract. Flexible pavement is extensively used in Malaysia as the construction cost of the pavement is lower compared to the rigid pavement. The uppermost layer of the flexible pavement called surface course, is made from asphalt bituminous mixture. This layer is a flexible layer where it can deform if subjected to great loads. The most popular defect that can be seen in flexible pavement is rutting. This study investigated the effect of Polypropylene (PP) fibre in influencing the behaviour and properties of the bituminous mixture when fully replaced as a filler and to evaluate the compressive strength of it. Marshall Mix Design was first used to obtain the optimum binder content and lastly, the specimens were compressed using Uniaxial Compressive Test machine to obtain its compressive strength. From the study, PP fibre reinforced bituminous mixture increased the compressive strength, the value of Marshall stability and help to reduce the flow. With all the stated effects, Polypropylene is ideal for replacing the conventional filler as it helps to strengthen the pavement layer and thus might be able to help save the maintenance cost for the constant repair of the conventional pavement layer.

1. Background
Flexible pavement and rigid pavement are generally the types of pavement construction of highways and roads around the globe. Both are designed with different materials and provide different strengths as the application of the design will be depended on the function of the road and also the predicted applied load.

The use of rigid pavement is more suitable for heavy and slow-moving traffic as it fulfils the criteria. It is possible to observe this situation around the toll area. A greater magnitude of loading would be imposed by getting slow-moving traffic on the surface. It is also a safer option to have a rigid pavement as it can withstand a higher load compared to the flexible pavement without significantly deforming.

Flexible pavement, on the other hand, is the most common form of pavement used for regular traffic flow. This type of pavement, however, when exposed to heavy loading, is not so great in strength. The uppermost layer is referred to as a surface course made of asphalt mixture that, when subjected to heavy loads, can deform easily. This condition will cause the road surface to have permanent defects.

As a consequence, a typical defect such as rutting can be seen to occur. Rutting is a type of defect that is triggered by the loading of the vehicle tyres on the pavement. It is typically parallel to the direction of the moving traffic. Without any repair, it will become more serious and could be unsafe to the user. In addition, the maintenance operation would cost the authority some money.
Nevertheless, this issue can be overcome by changing the intensity of that particular layer. Modification on the bituminous mixture is one of the alternatives that can be done. By increasing its tensile strength to the acceptable level, it will help to reduce the severity of the defects.

Fibre is one of the materials that can be used in bituminous modification. The addition of fibre in the bituminous mixture might be able to increase the strength of the pavement. Shanbara et. al [1] stated that the use of fibres in mixtures of asphalt as a reinforcement material provides a successful development in the interaction between aggregates and mastic that able to prevents crack formation and spread which eventually prolongs the service life of the pavement.

Different types of fibres relatively from natural to polymer fibres are available to choose from. According to Kamaruddin & Napiah [2], the addition of polymer fibres to the bituminous mixtures has altered the rheological properties and behaviour of the resulting binder, resulting in a higher optimum content of bitumen for the mixture.

One of the well-known polymer fibre is Polypropylene (PP). Polypropylene fibre is one of the cheapest fibres that can be easily found in Malaysia and also has good tensile strength. According to Galli [3], PP fibre is the popular fibre that is available. The properties of the fibre possessed by the PP make it an acceptable fibre to be studied. Some of the PP attributes that can be defined are as follows:

a) Strong tensile strength: help to reduce the deformation of the layer by increasing its load capacity.
b) Resistance to chemical attack: help protect the layer from any chemical threat.
c) Easy processing: does not contribute any problems at the stage of processing and requires low processing costs.
d) Recyclable: the source of PP can be obtained from fresh and recycled sources.

In addition to the general properties described above, there are also engineering properties of PP, such as low temperature and impact resistance, which make it very suitable for this study [3]. By having these properties, the strength and load capacity of the flexible pavement would be improved by adding PP into the mixture.

I.I. Filler
Natural fillers are the aggregate that passes 75μm [4]. Some of the available fillers are fly ashes, hydrated lime, and also quarry dust. The quarry dust is commonly used as a filler in Malaysia. As specified in the JKR Standard Specification for Road Works [5], the filler will be included in the mixture up to 2% of the total weight of the aggregates in which it is treated as an anti-stripping agent. By mixing the filler to the mixture, the fine grain of the filler that is smaller than the bitumen film on the aggregates will serve as a carrier (binder extender). According to Kandhal [6], the very fine filler makes the mixture act as though there were even more binders to increase the adhesion between the binder and the aggregates. Excessive quantity of filler contributes to an increase in stability, brittleness and a tendency to crack [7].

Therefore, this study was conducted to establish the optimum binder content (OBC) of unmodified and modified bituminous mixture, which was completely substituted by PP fibre as a filler, as well as to evaluate the compressive strength efficiency of both specimens.

Various experiments have been performed in the previous studies on the bituminous mixture combined with PP fibre as a filler. However, most of them have only been partly replaced. In this study, therefore, the modified specimens were completely replaced by PP fibre as a filler in the bituminous mixture.

The specimens were tested with the Marshall Apparatus Test to obtain the Marshall stability and flow value, the percentage of unit weight, the percentage of air void, the percentage of void filled with mineral aggregates, and also the percentage of void filled with bitumen. The data was analysed and the OBC was determined for both mixtures. Using the obtained OBC, specimens have again been prepared for further testing. Using Uniaxial Compressive Test machine, the maximum compressive load for both mixtures was recorded. Throughout the end, the OBC value, Marshall stability and flow value and the overall compressive load for both mixtures were evaluated.
2. Materials

2.1. Aggregate
In this study, the gradation of aggregate used was ACW14 consisting of coarse and fine aggregate. The particle size distribution, or gradation of aggregate, is one of the most influential aggregate characteristics in determining how it will perform as a pavement material. The aggregate was obtained from the quarry in Penanti, Penang.

2.2. Filler
The mineral filler used in the study was quarry dust, as used only in the unmodified bituminous mixture. Originally made of crushed stone, it has natural materials which pass through the No. 200 sieve (75 microns meter). As for the modified mixture, PP fibre M-06 was used. The size of the PP fibre used was 30 mm in length with the weight of 2% from the aggregate weight. The source of PP fibre used was from the manufacturing product, as the supply of these products is strong and convenient to obtain. Figure 1 below displays the PP fibre used in this study.

![Polypropylene fibre.](image)

2.3. Binder
The asphalt binder, often referred to as bitumen, is the most important component in the bituminous mixture where it acts as a binder between the aggregate that holds the pavement structure together. The binder grade used in this study was 60/70 PEN grade. The percentage of bitumen used for each specimen was 4-6% with 0.5% increment.

3. Methodology

3.1. Preparation of samples
For the determination of the OBC, 15 specimens of each unmodified bituminous mixture containing quarry dust and modified bituminous mixture (PP fibre filler) were prepared. The dry mixing method was used in this study, where PP fibre was blended with hot aggregates prior to mixing with bitumen. The preliminary mixing of the bituminous mixture was conducted using a laboratory-scale mixer at a temperature of 160°C. The heated mixture was then put in the Marshall Compaction mould. Specimen compaction was conducted using Marshall Compactor with 75 blows per side of the specimen.

3.2. Marshall mix design
In the Marshall Mixing Design process, 3 compacted specimens were prepared for each percentage of the binder content. The following tests were carried out on all the compacted specimens: (a)
determination of bulk density, (b) study of density and voids, (c) stability and flow tests. The criteria for Marshall Stability Flow is set out in the standard specification ASTM D 1559. The OBC was then determined based on the obtained result. Figure 2 shows the Marshall Apparatus.

Figure 2. Marshall apparatus.

3.3. Compression test
The method of using the Uniaxial Compressive Test machine was used to evaluate the compressive strength of the bituminous mixture after obtaining the OBC value for both types of specimens. A total of 6 specimens, each containing 3 unmodified and modified mixtures have been prepared. The test procedure and instructions have been set out in ASTM D 1075-007.

4. Analysis and discussion
According to Hot Mix Asphalt, Mixture Design and Construction Handbook [8], Method 1 is the most widely used and recommended by NAPA. By using this approach, the OBC value will be obtained by using 4 graphs from the Marshall volumetric properties graphs consisting of air void vs. binder content, flow vs. binder content, stability vs binder content, VFA vs. binder content and VMA vs. binder content as shown in figure 3 and 4. From the graph of air void vs. binder content plotted, the OBC was determined by corresponded to the median air void content (4%) of the specifications. The OBC for the unmodified mixture obtained was 5.7%. The 5.7% OBC was then used to determine the value of stability, flow, VFA and VMA from the graph.

Figure 3. Marshall Volumetric Properties (Unmodified Mixture).
Table 1 below is the summary results based on the OBC obtained. From Table 1, the stability for the unmodified mixture was 14800 N which was sufficient enough compared to the JKR requirement of > 8000 N. As for the flow value, the result recorded 3.85 mm still within the range of 2.0 – 4.0 mm as per requirement. The VFA and VMA recorded at 76% and 13.82 respectively.

Table 1. Properties Specification (Un-modified Mixture).

|                       | JKR Specification | Result  |
|-----------------------|-------------------|---------|
| Marshall Stability    | > 8000 N          | 14800 N |
| Flow                  | 2.0 - 4.0 mm      | 3.85mm  |
| Void filled with Asphalt cement, VFA | 70 – 80%         | 76%     |
| Void in mineral aggregate, VMA | None required     | 13.82   |
| OBC                   | 4 – 6%            | 5.7%    |

Figure 5 below shows the result obtained for the modified mixture. The OBC obtained from the graph was 5.9%, a slight 0.2% higher than the conventional mixture. This shows that the complete replacement of the mineral filler with PP fibre increased a bit in percentage of the OBC. However, the value of stability presented a significant increase by more than 5000 N compared to the unmodified mixture. Also, the decreased in flow proved that the PP fibre is able to provide stronger intact between the mixtures.
Table 2 presents the summary results based on the OBC obtained. As can be seen, all the results obtained met the requirement by JKR Standard Specification for Road Works. The significant increase for the stability shows that the PP fibre is able to increase the strength performance of asphaltic concrete.

**Table 2. Properties Specification (Modified Mixture).**

|                          | JKR Specification | Result  |
|--------------------------|-------------------|---------|
| Marshall Stability       | > 8000 N          | 20050 N |
| Flow                     | 2.0 - 4.0 mm      | 3.5 mm  |
| Void filled with Asphalt cement, VFA | 70 – 80%     | 70      |
| Void in mineral aggregate, VMA | None required   | 15.8    |
| OBC                      | 4 – 6%            | 5.9 %   |
As for the compression test, the maximum compressive load that can be catered by both bituminous mixture is shown in Table 3 below.

**Table 3: Comparison of maximum load.**

| Maximum Load (kN) | Unmodified Mixture | Modified Mixture |
|------------------|-------------------|------------------|
|                  | 33.85             | 54.45            |

From the result shown, it has been seen that the modified bituminous mixture can take on a higher load compared to the unmodified bituminous mixture. As can be shown, the modified mixture can take up to 20 kN of extra load compared to the unmodified mixture. This result has shown the essential parameter to change the behaviour of the pavement mixture if the mineral filler is modified. PP fibre is capable of helping to promote the compressive strength of the bituminous mixture. By possessing this property, the modified pavement layer will be less affected by the defect due to high traffic loads. In that regard, this particular result has proven that the modified bituminous mixture consisting of PP fibre can withstand a higher traffic load.

5. Conclusion
The following conclusions can be wrapped based on the results in this study:

- The PP fibre filler for the modified mixture requires a bit higher content of bitumen compared to the unmodified mixture of quarry dust filler. The OBC value for the modified and unmodified mixture was 5.9 percent and 5.7 percent, respectively. Less binding material tends to minimise building costs. In this case, the binder material of the conventional approach tends to have a strong performance.
- The stability value for the modified and unmodified mixtures was 20050 N and 14800 N respectively. A higher stability value indicates good strength performance in a bituminous mixture.
- The flow value of the modified and unmodified mixture also indicates certain variations of 3.5 mm and 3.85 mm respectively. Lower flow value helps to ensure that the mixture does not displace during construction and even when it is open to the public.
- The maximum measured compressive load that can be withstood by the modified and unmodified mixture was at 54.45 kN and 33.85 kN respectively. This finding, again, supports the idea that the modified bituminous mixture with PP fibre filler can withstand a higher load compared to the unmodified bituminous mixture.

In short, the modified bituminous mixture with the PP fibre filler showed a positive result in terms of Marshall stability, flow and also compressive strength. As a result, it is agreed that PP fibre is ideal for replacing quarry dust as a filler in a bituminous mixture with a slight modification required to minimise the percentage of OBC for modified bitumen.

6. References

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