Evaluating the mechanical properties of thin asphalt overlay incorporating reed ash

Nadia Abduljabbar 1, Shakir Al-Busaltan 2, Anmar Dulaimi 3, 4, 5

1 MSc student, University of Kerbala, Karbala, Iraq, Nadiaabduljabbar30@gmail.com
2 Assist. Prof. Dr, Faculty member, University of Kerbala, Karbala, Iraq, s.f.al-busaltan@uokerbala.edu.iq
3 Dr, College of Engineering, University of Warith Al-Anbiyaa, Karbala, Iraq, a.f.dulaimi@uowa.edu.iq
4 Ministry of Education, Karbala, Iraq
5 Department of Civil Engineering, Liverpool John Moores University, Liverpool, UK, A.F.Dulaimi@ljmu.ac.uk

Abstract. Thin Asphalt Overlay (TAO) is a preservation maintenance technique that has been shown to overcome shortcomings in the functional properties of surface pavement layers. Although TAO is not a structural layer, its application sustains the pavement’s structural strength and increases its lifespan, which is a valuable effect for the paving industry. Due to recent realisation of the limits of natural resources and the high cost of raw materials, the paving industry has also developed a secondary target of incorporating waste materials as an alternative to conventional raw materials, both to reduce environmental pollution and minimise costs, in such applications. This study focuses on evaluating the effect of using reed ash (RA) in this manner on the mechanical properties of TAO. The control TAO mixture was densely graded, with a 9.5 mm nominal maximum aggregate size (NMAS) utilising a 40/50 asphalt binder grade. Three percentages of RA were incorporated, 6%, 12% and 18%, to produce modified asphalt binder. To verify the effect of this material on cracking behaviours, resistance to permanent deformation of TAO, indirect tensile strength, creep compliance, and wheel track tests were carried out on both control and modified asphalt mixtures. The results showed a significant enhancement in the performance of TAO modified with 6% RA as compared to the control mixture, although the very high dosage of 18% reduced the performance of the relevant TAO mixtures. This study thus indicates that using this waste material can offer an alternative solution for asphalt cement modification, increasing sustainability, if dosages are carefully controlled.

Keywords: Biomass material; by-product materials; fly ash; hot mix asphalt; modified binder; waste materials.

1. Introduction
Thin asphalt overlay (TAO) is mainly used to preserve pavements showing minor signs of distress such as raveling, shallow rutting, aging, bleeding, minor cracking, and skid resistance problems. It is thus applied to obtain better performance and to increase the service life of the existing pavement [1]. Due to its low lift thickness, high cracking has been observed on TAO layers, however [2-4], and research into developing cracking resistance without any impact on other properties has thus attracted a great deal of interest among paving specialists. To enhance the function of TAO in the maintenance and protection of pavements and to
increase its resistance to external conditions, however, many developments must be adopted in all aspects, including material selection, mix design, and construction methods [5]. The modification of asphalt cement is a promising approach for improving the characteristics of the asphalt mixture and consequently increasing the resistance of pavement to rutting and fatigue cracking, as suggested by Nuñez et al. [6]. Extensive attempts have thus been made to upgrade TAO mixtures [7, 8].

Using waste materials is a sustainable and attractive solution to such issues, as it contributes to reducing the cost of disposal of waste and minimises environmental pollution, as well as contributing to the conservation of resources [9-14]. Several waste materials have already been used successfully as aggregate, filler and asphalt modifiers in asphalt mixtures, with options including recycled aggregates, waste brick, glass, seashells, reclaimed asphalt pavement, and waste tire rubber [15, 16]. Many researchers have thus used different types of waste and by-products to modify asphalt mixtures in multiphase application processes: Eme and Nwaobakata [17] recorded that modifying asphalt binder using waste low density polyethylene decreased the penetration and increased the softening point of asphalt binder, while Dulaimi et al. [18] reported that utilising cement and waste aluminosilicate material enhanced the stiffness modulus and water susceptibility of cold asphalt mixtures. Kadhim et al. [11] stated that the durability and mechanical properties of asphalt could be enhanced by the use of crushed glass as a fine aggregate in cold mix asphalt, while Chen et al. [19] indicated that using recycled fine aggregates powder (RFAP, a by-product of the production of recycled concrete aggregate) as a filler in asphalt mixtures could improve several properties of such asphalt mixture, including fatigue resistance and water sensitivity. Dulaimi et al. [20] also concluded that using waste calcium carbide residue (CCR) instead of limestone filler in hot mix asphalt improved the stiffness and increased the resistance to permanent deformation, offering significant improvement in resistance to crack initiation and crack propagation as well as enhancing the resistance against moisture damage.

Fly ashes are often used in the asphalt industry improve performance, reduce costs, and minimise environmental effects [21, 22]. Al-Merzah et al. [12] stated that replacing a proportion of ordinary Portland cement with palm leaf ash improved the mechanical properties of cold bitumen emulsion mixtures, while Sharma et al. [23] investigated the effects of four types of fly ashes collected from 14 thermal power plants with regard to their different physical and chemical characteristics when used as filler in asphalt mixtures. The main finding of the latter study was that the phase angle of the modified binder generally decreased with the increase in filler content, suggesting that an increase in filler content improves the elastic behaviour of the binder and thus increases the resistance to permanent deformation. All four fly ashes investigated increased the stiffness of asphalt binder and showed better resistance to water damage as compared to that of the conventional filler (stone dust). Similarly, the use of Date Seed Ash (DSA) as a bitumen modifier has been shown to act as an enhancer to resistance to fatigue behaviour in both asphalt binders and mixtures [24]. Tahami et al. [25] studied the influence of both Rice Husk Ash (RHA) and DSA on the properties of asphalt mixture, concluding that using these materials as fillers increased the viscosity, Marshall stability, and the stiffness modulus of asphalt mastics; they also further improved the resistance to rutting and fatigue life of asphalt mixtures by increasing the adhesion between asphalt binder and aggregate.

Mixing reed ash (RA) with asphalt binder decreases the penetration and ductility, while increasing the softening point of the asphalt binder. The Marshall stability is increased, while flow, air voids, voids in mineral aggregate, and voids filled with asphalt are decreased [26]. Mahdy et al [27] stated that modifying asphalt binder with RA could improve the skid resistance of asphalt mixture, while Abduljabbar et al. [7]
concluded that the resistance to abrasion loss of RA modified TAO mixtures was improved for mixtures modified by 6% and 12% RA, but that the resistance to abrasion loss reduced significantly with further increases in RA content up to 18%. However, very little research has been done on RA’s role in improving the performance of TAO mixtures.

RA is thus the waste material used in this research. Reeds are grown in large quantities on the banks of drainage channels and marshes in the middle and southernmost parts of Iraq, and quantities of reeds are removed and burned or disposed of randomly throughout the year. This destruction causes great damage to both the environment and human health. This study thus aims to both identify the mechanical properties of TAO mixtures modified with different ratios of RA and to support the principle of sustainable management if these resources to prevent this ongoing damage.

2. Materials and Mix Design
The materials used in this investigation were locally provided. The asphalt cement was 40/50-penetration grade, from the Al-Nasiriya factory. The important properties of this asphalt are summarised in Table 1.

| Property                              | ASTM designation | Test results | GSRB requirements |
|---------------------------------------|------------------|-------------|------------------|
| Penetration, 100 gm, 25 °C, 5 sec (1/10 mm) | ASTM [28]        | 45.5        | 40-50            |
| Specific Gravity, 25 °C, (gm/cm³)      | ASTM [29]        | 1.03        | -                |
| Ductility, 25 °C, 5 cm/min (cm)        | ASTM [30]        | 140         | >100             |
| Flash point, °C                        | ASTM [31]        | 315         | >232             |
| Softening point, °C                    | ASTM [32]        | 48.5        | -                |
| Solubility in trichloroethylene, %     | ASTM [33]        | 99.6        | >99              |

Both natural fine and coarse limestone aggregate were sourced from Karbala quarries. Dense graded surface course type III B with 9.5 mm nominal maximum aggregate size (NMAS) was selected for the TAO mixture to achieve the requirements of the General Specification for Roads and Bridges (GSRB), section R9 [34]. The middle gradation was selected for the TAO, as shown in table 2. Two types of fillers were used, measured as percentages of total aggregate weight, being 5.5% conventional filler (CMF) and 1.5% hydrated lime (HL), with the latter added as an antistripping agent according to GSRB [34]. The physical properties of the course and fine aggregates are presented in Table 3.

The samples were prepared according to the Marshall mix design procedure, as described in D6926 [41]. Aggregate and asphalt binder were mixed at a temperature of 165 °C, then the mixture was placed in Marshall moulds and compacted using 75 blows of a Marshall hammer to each face. The compaction effort undergoes change according to the percentage of air voids required for a specific test. To find the optimum
asphalt content (OAC), three samples were prepared for five different bitumen contents (4, 4.5, 5, 5.5, and 6 % by total weight of the mixture. The OAC was thus found to be 5.3%.

Table 2. Aggregate gradation.

| Sieve size | mm  | % passing by weight according to GSRB | Selected % passing by weight for tested TAO (mid-range GSRB specification) |
|------------|-----|---------------------------------------|-------------------------------------------------------------------------|
| ¾          | 19  | -----                                 | -----                                                                   |
| ½          | 12.5| 100                                   | 100                                                                     |
| 3/8        | 9.5 | 90-100                                | 95                                                                      |
| No. 4      | 4.75| 55-85                                 | 70                                                                      |
| No. 8      | 2.36| 32-67                                 | 49.5                                                                    |
| No. 50     | 0.3 | 7-23                                  | 15                                                                      |
| No. 200    | 0.075| 4-10                                  | 7                                                                       |

Table 3. Physical properties of course and fine aggregates.

| property                               | ASTM designation | GSRB limitations | Obtained value |
|----------------------------------------|------------------|------------------|----------------|
| Physical properties of coarse aggregates |                  |                  |                |
| Bulk specific gravity, gm/cm³          | ASTM [35]        | -                | 2.6            |
| Water absorption, %                    | ASTM [35]        | -                | 1.36           |
| Percent wear by Los Angeles abrasion, % | ASTM [36]        | 30% max          | 9.1            |
| Clay lumps, %                          | ASTM [37]        | -                | 0.05%          |
| Passing sieve No.200, %                | ASTM [38]        | -                | 0.91%          |
| Physical Properties of Fine Aggregates  |                  |                  |                |
| Bulk specific gravity, gm/cm³          | ASTM [39]        | -                | 2.64           |
| Water absorption, %                    | ASTM [39]        | -                | 0.7            |
| Clay lumps, %                          | ASTM [37]        | -                | 1.9%           |
| Passing sieve No.200, %                | ASTM [38]        | -                | 3.52%          |
| Sand equivalent, %                     | ASTM [40]        | 45% min          | 49%            |
3. Asphalt Cement Modification

The RA used in this study was prepared by burning collected reeds onsite to reduce their volume; the product was then brought to the laboratory and burned again in an oven at 900 °C for 2 hours, as indicated by Mirhosseini et al and Al-Shafi’I et al [42, 43]. After that, a mechanical grinder was used to grind the resulting material for 60 minutes. The ground ash was sieved using a No.200 sieve. Figure 1 shows images of the RA preparation, while the chemical and physical properties of RA are demonstrated in Table 4.

Asphalt binder was poured into a mechanical shear mixer after being heated to 160 °C. RA was then added gradually into the shear mixer pan with the mixer operating at a rotation speed of 1,500 rpm. The duration of mixing was 30 minutes at 150 °C, creating a homogeneous blend. Three blends were prepared with different proportions of RA (6%, 12%, and 18% of the total weight of asphalt cement). These ratios are similar to those used by many researchers in this area [42, 44]. Table 5 shows the mixture designations by RA content.

![Figure 1. RA preparation.](image-url)
Table 4. Chemical analysis and physical properties of RA.

| Chemical compositions |  |
|-----------------------|---|
| SiO₂                  | 72.05 |
| Al₂O₃                 | 7.740 |
| Fe₂O₃                 | 0.973 |
| CaO                   | 8.280 |
| MgO                   | 0.808 |
| K₂O                   | 7.093 |
| Na₂O                  | 1.664 |

| Physical properties |  |
|---------------------|---|
| Specific surface area (m²/kg) | 1339 |
| Density (gm/cm³)     | 2.5 |

Table 5. Details of asphalt mixtures.

| Mixture symbol | RA content, % |
|----------------|---------------|
| M0             | 0             |
| 6R             | 6             |
| 12R            | 12            |
| 18R            | 18            |

4. Experimental work
Several laboratory tests were conducted to evaluate the performance of the mixtures produced in terms of resistance to cracking, creep compliance, and rutting resistance. These tests were done as follows:

4.1 Indirect Tensile Strength Test (ITST)
The ITST test measures the resistance of asphalt mixtures to cracking. In conducting the test, AASHTO T283 [45] was followed. This specification recommends that the air voids ratio should be 7 ± 0.5%, which is achieved by controlling the number of Marshall hammer blows until the required air void ratio is reached.
Three specimens were prepared for each asphalt mixture type and tested at 25 °C using the ITST device by applying loads at a rate of 50 mm/min until the largest load is achieved.

4.2 Creep Compliance Test (CC)
CC can be defined as a time-dependent strain divided by stress. To test this, AASHTO T322-03[46] was followed. This test is commonly used for evaluating the rate of accumulated damage in asphalt mixtures. The specification again recommends that the air voids ratio should be 7 ± 0.5%. The sample was thermally controlled at (0 °C) and subjected to a static load along a diametric axis, for a specified period of time (1,000 seconds). During the loading period, linear variable differential transducer (LVDT) sensors were used to measure the vertical and horizontal deformations.

4.3 Wheel Tracking Test (WTT)
The viscoelastic behaviour of the asphalt mixture means that when it is subjected to load, it will be deformed after the load is removed, and while part of this deformation will be recovered, a small part will not. Rutting is thus accrued when this unrecovered deformation accumulates over time. To measure the rut depth of the control and modified mixtures, a wheel tracking device, designed according to BS EN 12697-22 [47], was applied. The device consists of a rubber wheel loaded with 700 N that moves in a straight line on the specimen for a specified number of cycles (10,000 passes) at a temperature of 60 °C. The rut depth is then measured using a vertical LVDT.

5. Results and Discussion
5.1 Results of the ITST
Figure 2 shows the effects of including RA in the binder used for the TAO mixture. It can be seen that 6% addition of RA increases the ITS by 21% compared to the control mixture, while mixtures with modified binder at 12% and 18% dosing show a slight reduction in ITS values, 3% and 22%, respectively. These results can be explained as follows: the initial increase in ITS is due to the effect of SiO₂, which works by increasing the adhesion between the asphalt binder and aggregate. The presence of SiO₂ improves the polarity of the asphalt binder, while the ability of the RA to absorb the light molecule weight components, increases the quantity of Asphaltene, which is reflected in the enhancement of binder stiffness. However, continuous increments of RA cause a reduction in ITS, potentially due to the high surface area and porosity of RA, which continues to absorb more light molecule weight components and thus increases the brittleness of the binder. This result is consistent with the results obtained by Al-Mehthel et al. [48], and suggests that a low percentage of RA is recommended to gain the best improvement in cracking resistance at intermediate temperatures.
5.2 Results of Creep Compliance Test (CC)

The relationships between CC and time for control and modified TAO mixtures at 0 °C are presented in Figure 3. The CC values increase as time increases, indicating a reduction in stiffness with loading time or a reduction in ability to resist fatigue and crack propagation. The additions of 6% and 12 % RA reduce the CC values by 33% and 28%, respectively, due to increases in the stiffness of the TAO mixture, as explained previously. Notably the 12% RA dose is enhanced as a result of testing temperature, on moving from intermediate to low temperatures. The addition of 18% RA still has an inferior effect, increasing the CC by 33% compared to M0, potentially due to a reduction in the adhesivity of asphalt binder. These results indicate that the resistance to crack progression at low temperature is sensitive to RA content, being highest at low RA percentages.
5.3 Results of Wheel Tracking Test (WTT)

Figure 4 shows the results of the wheel tracking tests for control and modified TAO mixtures. The rut depth increased with the increase in cycle number and decreased on modifying the asphalt mixture with RA. Rut depth decreased by 42%, 28.5%, and 14% for 6R, 12R, and 18R, respectively, indicating that using RA to modify asphalt binder can increase the stiffness of asphalt mixtures under wheel loading, especially at low dosages. However, the improvement in binder stiffness is also reflected in the dynamic modulus and rate of rut, as seen in figure 5. Similar results were offered by Korayem et al [49], who suggested that absorption and polarity changes were responsible for the improvement in binder stiffness, implying that incorporating RA in the binder used for TAO is a promising means of overcoming the permanent deformation problems of TAO. The reduction in rut depth at elevated temperatures also indicates that this mixture also offers high performance in a hot environment [20].

![Figure 4](image1.png)  
**Figure 4.** Relationship between rut depth and the number of passes for control and modified TAO mixtures.

![Figure 5](image2.png)  
**Figure 5.** The relationship between dynamic stability, rutting increase rate, and RA content for control and modified TAO mixtures.
6. Conclusions
Incorporating biomass materials to enhance asphalt mixtures using a sustainable approach has been investigated by several different researchers. This study aimed to evaluate RA as a proposed biomass enhancer more specifically for TAO. According to testing of the mechanical properties for modified and unmodified TAO mixtures, the following conclusions can be drawn:

1. Cracking resistance at an intermediate temperature, in terms of indirect tensile strength, is improved at low RA dosing ratios, with an improvement of up to 21% compared with the control TAO mixture. However, higher dosages of up to 12% and 18% reduce resistance to cracking by 3% and 22%, respectively.
2. The resistance to low temperature cracking and crack progression is improved by incorporating RA in asphalt binder at up to a 12% proportion. CC increased significantly, by 33% and 28%, for TAO mixtures with 6% and 12% RA modified binder, respectively. However, the higher dosage created inferior TAO mixtures due to a reduction in CC by 33% as compared to the control mix.
3. Rut resistance is improved significantly by incorporating RA into asphalt binder for TAO mixtures. The rut depth decreased noticeably due to an increase in the resistance to permanent deformation, by 42%, 28.5% and 14% for mixtures comprising 6, 12, and 18% RA modified binder, respectively.

In general, the moderate incorporation of RA positively enhances mechanical properties of TAO mixtures; this is thus a very promising approach, but further testing of other properties is required. A site investigation is also recommended to explore the practical challenges of such a modification process.

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