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Formulation of Bio-Asphalt Through Utilization of Tar Residues Bio-Oil from Waste Coconut Shell Pyrolysis with Biochar and Steam Pine Tree Sap to Support Sustainable Tourism Sector

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Abstract

Tourism is one of the most potential sectors in Indonesia. Minister of Tourism and Creative Economy, Sandiaga Uno released a total value of tourism sector in September 2023 reached total of USD6 billion, and contributed 3,76% to PDB. Forbes International named Indonesia as the most beautiful country based on the quality and total of natural panoramas per 1000 km^2. It is also surrounded by beautiful cultures, creatures, and foods that attract local and international tourists to visit. To support this sector, good infrastructure is needed as one of the services given to our tourists. One of the infrastructure issues in Indonesia is the feasibility of roads. In 2021, Land Transportation Statistics recorded that 31.9% of roads were damaged and 15.9% were seriously damaged. This is caused by the high production costs for producing the best quality asphalt followed by the scarce availability of petroleum as the raw material. Therefore, renewable alternative materials and methods are needed which is simple in the production process. On the other hand, coconut shell waste has not been optimally utilized in Indonesia and provides increased waste which is difficult to deal with. There is a pyrolysis method for processing this waste. This research aims to obtain bio-asphalt products which able to compete with oil asphalt, using the main ingredient of tar (bio-oil) as the result of coconut shells pyrolysis as well as additives in the form of biochar and steam pine tree sap. This research was carried out in three stages, namely pyrolysis, distillation and mixing. The pyrolysis stage is carried out at a temperature range of 300-400°C to obtain bio-oil. The distillation stage is carried out at a temperature of 250°C to obtain tar. Furthermore stage of mixing tar with biochar and steam pine tree sap additives. The mixture consists of 30% tar and 70% petroleum asphalt. The variation used is the type of additive and the percentage of additive composition to obtain the most optimal bio-asphalt formulation. Bio-Asphalt's product almost meets five parameters existing, with a penetration value of 60/70, ductility of 132.33 mm, the softening point of 52.8°C, and the flash point is 254°C, meanwhile specific gravity which does not meet it is 0.965 gr/cc. Therefore, this research is a solution for economical asphalt production so that the tourism sector can be stronger and sustainable.

Keywords: Tourism; Creative Economy; High Production cost; Bio-Asphalts Product; Indonesia

1. Introduction

Tourism is one of the most potential sectors in Indonesia. Minister of Tourism and Creative Economy, Sandiaga Uno released a total value of the tourismsector in September 2023 total USD6 billion, and contributed 3,76% for PDB. Forbes International named Indonesia as the most beautiful country based on the quality and total of natural panoramas per 1000 km^2. It is surrounded by beautiful cultures, creatures, and foods that attract local and international tourists to visit. To support this sector, good infrastructure is needed as one of the services given to ourtourists. One of the infrastructure issues in Indonesia is the feasibility of roads. In 2021, Land Transportation Statistics recorded that 31.9% of roads were damaged and 15.9% were seriously damaged. Project improvement and construction of roadsections in Indonesia is currently still being pursued, but in its implementation, the main raw material is needed, namely petroleum asphalt as an adhesive agent and filler.

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The role of petroleum asphalt is very important in road pavement, but the availability of petroleum sources in Indonesia is currently running low. Pre- pandemic petroleum reserves by the Central Bureau of Statistics (BPS) from 2018 to 2019 experienced a 49.8% decrease, which was originally 7.53 billion barrels to 3.77 billion barrels.

The energy crisis has another side that can be attempted as a breakthrough in the utilization of renewable energy, namely biomass waste. As a country that is rich in natural resources, it means that it has a huge biomass potential. BPS noted that in 2021, coconut production reached 2.85 (BPS, 2021). This plant is nicknamed the "Tree of Life" because every part of it can be utilized. However, along with this also provides an increase in coconut shell waste which is quite difficult to overcome. A solution is presented, namely the use of the pyrolysis method for biomass waste. This pyrolysis process converts biomass waste such as wood, straw, and other organic wastes into a liquid product that has the properties of asphalt that can be useful in pavement. This pyrolysis method is simple and easy to apply to the community as well as with tools that are easy to obtain from around. In addition, this method produces three products namely biogas, biochar, and bio-oil where the three products can be utilized as alternative energy sources.

The commonly desired product in this process is bio-oil, but unfortunately, the simple pyrolysis of woody materials produces more residue when in the form of liquid smoke. This is because the equipment used makes it difficult to adjust the variable temperature so that during combustion, tar is also obtained. Tar, which is the residue in the liquid smoke, is obtained after passing through the distillation process. Tar from liquid smoke distillation (also known as bio-tar or bio-liquid tar) has emerged as a potential candidate to partially or fully replace petroleum asphalt in road pavements commonly referred to as bio-asphalt. Tar is a heavy fraction with solid black, viscous, and sticky physical properties. It has similar characteristics to petroleum asphalt, but chemically, tar residue from distillation is still less than optimal when used as a filler or adhesive when directly substituted for petroleum asphalt. Shortcomings in the use of tar as a bio-asphalt replacement for petroleum asphalt are in the plastic properties and strength. This is why the formulation of tar and additives are needed to improve the quality of bio-asphalt.

The availability of resources in Indonesia provides the potential to use organic materials such as steam pine tree sap as additives in bio-asphalt. Steam pine tree sap is also known as Gondorukem which has passed the distillation process (Akbar et al., 2015). This material is solid at room temperature and has good adhesive and hardening properties. In addition, another product of pyrolysis biochar can also be utilized as an additive in strengthening the asphalt structure. This is because biochar from pyrolysis has a water content of <5% and carbon >70%. So in its use biochar and steam pine tree sap can dissolve in bio-asphalt formulations and add to the sturdiness of the asphalt structure which will act as a binder and filler. Therefore, It is hoped that this bio-asphalt formulation can produce asphalt that has the same quality equivalent to petroleum asphalt. Through each ingredient used, it has been shown that there is an effort to be responsible for consumption that produces biomass waste as well as an effort to produce an environmentally friendly product from every remaining material. This research can be a great solution to create a stronger and more sustainable tourism sector in Indonesia.

2. Literature Review

2.1. Biomass of Waste Coconut Shell

Biomass has gained great attention as a renewable energy source that has the potential to reduce our dependence on fossil fuels. One of the promising biomass waste is coconut shell. Coconut shells are categorized as hardwood but have a higher lignin content and lower cellulose content. South Sumatra Province recorded a high level of coconut production in 2022, reaching 58,039 tons (BPS, 2023). The high number of coconut trees in the province is closely related to the volume of coconut shell waste generated during the coconut meat extraction process. Harsono (2018) noted that for every 58.3 kg of coconut fruit, around 19.3 kg or about 33% of the fruit turns into shell waste.

Coconut shells are commonly used as handicrafts, fuel, and raw materials for activated charcoal. The process of making charcoal from wood biomass waste produces smoke as a combustion effect, this smoke is utilized as liquid smoke by changing it from the gas phase to the liquid phase by the condensation process. One of the main components of liquid smoke is tar. Tar contained in liquid smoke includes fractions of smoke containing complex organic compounds, usually in the form of oily and sticky substances. Coconut shell is one of the potential raw materials for liquid smoke because of the substances contained in it as shown in Table 1.

Table 1. Chemical Composition of Coconut Shell

Composition	Wt%
Lignin	29,4
Pentosa	27,7
Selulosa	26,6
Water	8
Extraction solvent	4,2
Uronat anhidrat	3,5
Ash	0,6

Reference: (*Husseinsyah and Mosthapa*, 2011)

2.2. Pyrolysis

There are various methods for tackling the problem of waste and processing it into an energy source, namely through biomass conversion. Biomass conversion is divided into two types of methods, namely biochemical (fermentation) and thermochemical (pyrolysis and gasification). Both of these methods have their own advantages, but when viewed in terms of process efficiency with increasing energy needs in Indonesia, pyrolysis-type thermochemical is the right choice. Pyrolysis is a method of decomposing biomass that has lignocellulose content through combustion but in the absence of oxygen. The advantage of this method is that it can be operated at a low-temperature range of 300-600°C (Basu, 2010). The three main products obtained from this method are biochar, biogas, and bio-oil. But in obtaining these three products that need to be varied are the temperature variables and the heating rate.

This method can be applied to the community, but its limitation is that it is not able to regulate the temperature in the production process. This has an impact on the stability of the process so that the purity of the product is disturbed. If the process temperature is too high, the quantity of bio-oil product increases along with the formation of tar. Conversely, if the pyrolysis temperature is too low, the quantity of biochar will dominate while the quality of bio-oil will contain more phenol compounds and water. Therefore, in this pyrolysis process, efforts are needed to utilize by-products and residues from disturbances in the main product so that the initial purpose of this process can be appropriate, namely promoting a sustainable system for producing energy.

2.3. Tar Residue Bio-Oil

Tar is a thick black and sticky compound, at high temperatures its phase will become liquid while at low temperatures tar changes its phase to solid. The depletion of petroleum availability presents a solution to the utilization of tar from renewable sources, namely biomass waste. The method that can be done is pyrolysis to obtain bio-oil which has a liquid phase as a result of biogas condensation. Pyrolysis that occurs at high temperatures produces more bio-oil products, but decreases the rendition of bio-oil products, and also decreases the yield due to secondary cracking of the tar. Tar from the bio-oil residue is a heavy fraction that cannot be dissolved in water. This event can occur when the lignin in the biomass has a high molecular weight, resulting in the formation of high molecular weight so that sediment is formed (Kusumawati, 2015) Tar from bio-oil residue has the potential to be used as an additional formulation to substitute petroleum asphalt. Biomass waste with characteristics must have a high lignin content which is believed to slow down the oxidation process of road asphalt which acts as a binder. However, its strength has not been able to replace petroleum asphalt completely. So in its utilization, it still needs to be juxtaposed with petroleum asphalt to see its potential use.

Research conducted by Kusumawati (2015), produces bio-aspal made from bagasse through the process of pyrolysis and bio-oil evaporation. But indeed in this process, the yield produced is only about 6.78% besides that based on the results of the IR spectrum, the content of this bio-aspal still has impurities. The advantage of this research is the simple evaporation process so that bio-asphalt can be directly obtained. However, the disadvantage is that the bio-oil produced should still contain other impurities that can be recycled. Therefore, the method of obtaining tar from bio-oil residue can be done through a distillation process with a temperature of 225°C so that inefficient energy utilization and every content in bio-oil can be utilized.

3. Research Method

3.1. Raw Material Preparation

Raw materials consisting of coconut shell waste, petroleum asphalt, and steam pine tree sap need to be prepared first. The coconut shell waste is cleaned and size reduced to the same size, then dried in an oven for 3 hours at 105°C to reduce the moisture content. The steam pine tree sap is then cleaned and crushed into fine powder. Meanwhile, petroleum asphalt is simply heated to a liquid phase.

3.2. Pyrolysis of Waste Coconut Shell

The dried coconut shell waste is then weighed as much as 5 kg, and used as a reactor feed in the pyrolysis process for 2-3 hours at a temperature of 300-400°C until the gas product is no longer formed. The results of pyrolysis in the form of biochar and bio-oil (raw liquid smoke) are collected. Biochar that has burned completely is then crushed until smooth and then sieved to a size of 50 mesh. Meanwhile, the bio-oil product is stored to pass the distillation process at a later stage.

3.3. Bio-oil Distillation

This distillation stage aims to evaporate the components bound in bio-oil to leave tar and other residues with heavy fractions. A total of 300 mL of bio-oil is put into a distillation flask whose heat source is oil with a temperature of 250°C for 3-3.5 hours. The mixture in the distillate flask evaporates and is condensed in a condenser. The vapor changes phase to liquid which is phenol, water, and other binder components. Meanwhile, the residue left in the distillate flask and not evaporated is called tar. The tar is pitch black in color and sticky in texture.

4. Results and Discussion

Each stage in this research contributes to forming an optimal product. The preparation stage of coconut shell waste, namely drying, can remove moisture content of about 20% of the total initial mass of waste. Then size reduction can expand the heat distribution surface during the pyrolysis process. Therefore, the lignocellulose decomposition process becomes easier. The pyrolysis stage of 5 kg of coconut shell waste for 2 hours with a temperature of 300-400°C can produce products consisting of 1.8 kg of biochar: 2 liters of bio-oil and uncollected biogas as losses. Biochar that burns completely is then sized reduction to expand the surface and spread evenly. Then the bio-oil is continued to the distillation stage to obtain bio-oil without phenol or water content to leave bio-oil and tar as the residue. The total volume of bio-oil obtained was 250 ml. Tar bio-oil residue obtained after the distillation process is 17 grams which is a heavy fraction, but its consistency is not as high as that of bio-oil residue. This is due to the origin structure in composing.

Aromatic hydrocarbons in tar tends to have looser bonds. Therefore, as a first step to material substitution, the right formulation is needed in the addition of additives both biochar and steam pine tree sap to the bio-asphalt mixture. The mixing stage of each raw material is carried out by melting petroleum asphalt and bio-oil distillation residue tar, then mixed based on the total mass percentage. Additives are introduced into the mixture without reference to the temperature of the material, this is what causes the distribution to be uneven. So that the product formed tends to be unstable at some point. Qualitatively, the addition of additives is to improve the mushy properties of tar residue from bio-oil distillation to become sturdier, high temperature resistant, and still able to plastic deformation to hopefully replace petroleum asphalt.

5. Conclusion

1. The addition of biochar additive to the mix contributed to the sturdiness at penetration values reaching 60/70 as well as the specific gravity that almostresembles, this is due to the pore surface and large surface area to form a solid bond.
2. Steam pine tree sap provides asphalt resistance to high temperatures wherethe A2 sample soft and flash points reached 51°C and 259°C. However, thehardness of this material is so small that it is easy to crumble.
3. This bio-asphalt superior product almost fill the five parameters, with apenetration value of 60/70, a ductility of 132.33 mm, a softening point of 52.8°C, and a flash point of 254°C. meanwhile the specific gravity that doesnot meet is 0.965 gr/cc.

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