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RECYCLING OF WASTE MATERIALS FOR PRODUCTION OF BITUMEN: A REVIEW

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ABSTRACT- Globally, waste management has been a growing concern. These items clog landfills and reduce available living space. The surrounding environment is contaminated by landfill leachate. Toxic airborne vapours are released into the atmosphere during traditional incineration. Researchers are always looking for new ways to manage and recycle waste in a sustainable fashion. The most efficient waste management strategies are recycling and reuse. Because diverse types of trash are recycled into asphalt concrete and bitumen, the pavement business is one potential area. The use of high-density polyethylene, marble quarry waste, building demolition waste, ground tyre rubber, cooking oil, palm oil fuel ash, coconut, sisal, cellulose and polyester fibre, starch, plastic bottles, waste glass, waste brick, waste ceramic, waste fly ash, and cigarette butts in asphalt concrete and bitumen is discussed in this paper. Many experts have looked at these waste elements and tried to figure out how to use them in asphalt concrete and bitumen. The results of some key studies have been analyzed in this work, and the scope for further exploration is highlighted.

Keywords- asphalt concrete; recycling; waste materials; environmental sustainability; advanced materials

1. INTRODUCTION

Every day, one million tonnes of rubbish are produced worldwide. The majority of this garbage ends up in landfills. Australia generated more than 27 million tonnes of trash between 2014 and 2015 [1]. Since 2007, landfill garbage has grown by 6 million tonnes [2]. Municipal garbage accounted for approximately 6.5 million tonnes of the 27 million tonnes of waste disposed of in 2014–2015, while commercial and industrial waste accounted for 13 million tonnes and building and demolition waste accounted for 7.1 million tonnes [1]. Modern and comfortable lifestyles, as well as technological advancements and industrialization, have increased the volume and diversity of trash produced, resulting in a major waste disposal dilemma [3]. Traditional trash disposal techniques are not necessarily effective or environmentally beneficial. One common trash disposal method is incineration. According to studies, CO2 emissions from incinerators are higher than those from coal, oil, or gas-fired power plants. Mercury, fluorides, sulfuric acid, nitrous oxide, hydrogen chloride, and cadmium are among the 210 types of hazardous substances produced by incinerators [4]. As the world's population grows, natural resources are depleted. The recovery of materials and energy from waste materials has gotten a lot of attention in recent decades, with the goal of finding a long-term solution to reduce natural resource exploitation and landfill utilisation [5]. In this millenium, sustainability is a booming field [6]. To ensure sustainability, the world needs to conserve its resources and find novel ways to recycle garbage [7].

The concept of trash recycling has spawned a major research industry. Different types of waste materials have been investigated with green material technologies to reduce environmental impacts and recycle trash in the building sector [4,8–10]. Roads and roads are an important asset management sector all over the world. The majority of highways are of the sort that can be changed [11]. Australia has over 350,000 kilometres of paved road and generates more than 10 million tonnes of asphalt concrete per year [12,13]. Up to 95% of asphalt concrete is made up of aggregates. As a result, using alternative aggregates into the manufacturing of asphalt concrete and bitumen can help alleviate the strain on the world's landfills while also promoting sustainable practices for future large road projects around the world.

2. ASPHALT CONCRETE

A popular type of pavement is flexible pavement. According to statistics, flexible pavement is used on 95 percent of all highways in the globe [7,14]. Flexible and stiff pavement are distinguished by the type of binder they use. Portland cement is used as a binder in stiff pavement, while bitumen is utilized in flexible pavement. Aggregates and bitumen are combined in asphalt concrete. Based on the gradation of the aggregates, hot mix asphalt (HMA) and stone mastic asphalt are the two basic kinds of asphalt concrete mix (SMA). A typical asphalt pavement's basic structure is shown in Figure 1.

Figure 1. Typical structure of asphalt pavement [15]

2.1. Hot Mix Asphalt (HMA)

The density of hot mix asphalt (HMA) can be dense or open. Dense-graded HMA has a smaller void ratio than open-graded HMA, as the name implies. To properly distribute through the asphalt concrete mix, dense-graded HMA comprises a vast variation of particle sizes. Furthermore, dense-graded HMA is the most widely utilised type of asphalt concrete in the world [16]. It is suitable for all traffic conditions. Because of its larger void ratio, which permits the mix to be more permeable, open-graded HMA is commonly employed in drainage layers [16,17].

2.2. Stone Mastic Asphalt (SMA)

A gap-graded HMA, stone mastic asphalt is widely utilised in Europe [17]. Because of their superior physical and mechanical qualities, which are required for the stone-to-stone contact structure, the aggregates used in SMA mixes are frequently of greater grade than the aggregates used in regular HMA mixes. The high coarse aggregate composition of SMA reduces rutting and increases structure lifetime [18].

2.3. Advantages and Disadvantages of Different Type of Asphalt

Table 1 shows a side-by-side comparison of HMA and SMA. Although different forms of asphalt have varied gradations, the basic elements are all the same. Open-graded aggregates and bitumen are utilised in the HMA process. Gap-graded aggregate, fibres, and bitumen, on the other hand, are employed in SMA [19].

Type of Asphalt	Advantages	Disadvantages
Hot mix asphalt (HMA)	Low cost Effective in all traffic conditions	Lower rutting resistance Shorter service life Lesser quality aggregates used
Stone mastic asphalt (SMA)	Long service life High resistance to deformation Increased fatigue testing life Noise-reductive properties Decreased water spray when raining	Low skid resistance High cost Increased risk of flat spots occurring due to the SMA design procedure

3. BITUMEN

Bitumen is a dark brown or black viscoelastic complex hydrocarbon. Despite the fact that there are a few natural sources of bitumen, most bitumen comes from crude oil refineries [20]. Bitumen is employed as the binder for flexible pavement construction all over the world due to its waterproof and viscoelastic properties. Bitumen is graded in three ways: penetration, performance, and viscosity. The classification of bitumen based on viscosity grade is becoming increasingly prevalent. With the exception of the polymer-modified bitumen (PMB) class, Figure 3 [21] shows the possible kinds for the construction of flexible pavements according to the Australian Standard (with a typical viscosity of bitumen of 60 °C).

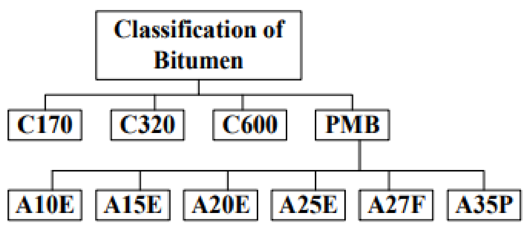

Figure 2. Classification of bitumen according to the Australian Standard for the construction of pavement

Researchers from all over the world are attempting to improve the qualities of these materials in order to ensure the industry's long-term viability [7,20,22]. Recycling waste materials for use in asphalt is widely acknowledged as a cost-effective way for improving pavement quality while also assisting in the management and recycling of various waste products [7]. The utilisation of various waste materials in bitumen has been studied by several researchers. For quite some time, plastic and polymer-based modifiers have been widely employed. For the construction of roads, many companies have turned to plastic rubber and polymer-modified bitumen [22–24]. Many researchers, on the other hand, have looked into the utilisation of common home leftovers such waste cooking oil in bitumen. They have advised an ideal amount of waste cooking oil in bitumen of up to 5% (by weight) in specific circumstances to ensure that any performance compromise is minimised [22,25]. In order to improve ageing resistance, researchers modified bitumen with palm oil fuel ash (POFA) and discovered that POFA in bitumen can act as a binder rejuvenator [22,26,27]. To address the worldwide waste management issue, various forms of fibre have been employed in construction materials [28]. Fiber has been reported to increase bitumen performance in several trials [28–31]. Researchers have looked into the use of synthetic fibres in asphalt concrete, such as polymer fibre, steel fibre, and carbon fibres [28]. Carbon fibre has been found to improve the electrical properties of asphalt while compromising the mechanical performance of asphalt concrete, whereas steel fibre improves asphalt stability [32,33]. During the transportation of the mix from the plant to the construction site, cellulose fibre is used to reduce binder drain-off [34,35]. Because cigarette butt filters are formed of cellulose acetate-based fibre, they could be utilised as a substitute for natural cellulose fibre in stone mastic asphalt. Recycling appropriate trash in bitumen in an environmentally sound manner is a long-term solution to the global waste management challenge [36].

4. WASTE MATERIALS USE IN ASPHALT MIX AND BITUMEN

Plastic, marble quarry debris, demolition waste, ground tyre rubber, waste cooking oil, palm oil fuel ash, coconut, sisal, cellulose, polyester fibres, starch, plastic bottle, waste glass, waste brick, waste ceramic, waste fly ash, and cigarette butts have all been examined. Recycling methods for asphalt concrete and bitumen were discussed. Sections that follow have been covered in the materials review-

(1) Waste material selection

(2) Origin, characteristics, and various applications

(3) Asphalt concrete and bitumen recycling methods

(4) A discussion of the performance of waste-based modified asphalt concrete and bitumen.

4.1 Plastic Waste

Plastic is one of the most commonly discarded materials on the planet. There are numerous types of plastic garbage. Plastic bags, bottles, cups, and straws are common sources of plastic garbage. Plastic is a non-biodegradable polymer-based substance. Plastic has been widely utilized as a household item around the world due to its low manufacturing cost, ease of transportation and storage, and waterproof nature.

As additions, many types of plastic waste have been employed in asphalt. In Turkey, researchers looked into the effects of a modified high-density polyethylene (HDPE) binder in hot mix asphalt (HMA). HDPE was combined with the bitumen content in quantities of 4%–6% and 8% (by weight of the optimal bitumen content) [37]. Marshall Stability, Marshall quotient (MQ), and flow were all higher in the processed sample. When HDPE-modified binder is used in asphalt mix, it increases resistance to permanent deformation while also assisting in the recycling of plastic waste. According to research conducted in Saudi Arabia, growing industrialization and rapid urbanization resulted in a rise in solid plastic trash. Authors investigated the effect of different types of plastic waste, including HDPE, in asphalt binders. Results showed an increase in resilience modulus, and a model indicated improvement in rutting and fatigue performance [38]. The difference between the various types of polymers like polyethylene, polypropylene, polyvinyl chloride, styrene-butadiene block copolymer, and styrene-isoprene block copolymer relates to the manufacturing process through polymerization. Each type of polymers stand alone in properties like hardness, viscosity, transparency, temperature susceptibility, color, and type of additive used. An artificial neural network study and as multiple linear regression analysis were carried out, aiming to predict permanent deformation of HDPE-modified asphalt mix. The model showed that up to 7% addition of HDPE waste materials in asphalt mixture reduced the final strain of the mixture and reduced permanent deformation under dynamic loading conditions [40].

4.2. Quarry Waste

Quarries in various places of the world produce huge amounts of garbage. Digging and blasting are required for mine exploration and the extraction of minerals and valuable stones from quarries, resulting in waste products and recoverable aggregates. Quarry aggregates have qualities and appearance that are very similar to ordinary aggregates. Researchers from Afyon Kocatepe Üniversity in Turkey discovered that industrial waste from marble quarries may be used to make asphalt pavement. The usage of aggregates produced from a marble quarry was spurred by increased demand for aggregate for the asphalt industry and deterioration of the overall roughness of the Earth's surface as a result of the search for new sources. Researchers compared waste aggregates from a homogeneous marble and andesite quarry to standard aggregates used in the asphalt paving industry. The aggregates' physical attributes are comparable to standard aggregates, according to the findings of this study. These aggregates can be used to make light- to medium-traffic asphalt pavement. Many waste products are generated by the mining industry. Proper innovation and processing methods can transform these wastes into resources. A huge volume of aggregates is needed for road and highway construction. Traditional granite and basalt aggregates are costly, thus many countries rely on them for road construction. Limestone mining waste in India was treated and reformed into various sizes using a gradation table. Up to 50% of typical basalt aggregates were replaced with aggregates obtained from mining waste in the preparation of asphalt mix samples. All the samples fulfilled Marshall Design parameters for low-volume roads. For a visual comparison, Figure 4 shows quarry waste and ordinary aggregate.

Figure 3. Quarry waste (left) and traditional aggregate (right)

4.3. Building Demolition Waste

Demolished buildings generate a significant amount of waste each day, as 90% of this waste is disposed of in landfills. A study in Kuwait showed the potential feasibility of demolished building waste for use in aggregates. In this study, Marshall Samples were prepared with aggregates obtained from demolition waste. All samples passed the standard requirements based on laboratory investigations. In Spain, researchers evaluated and investigated laboratory and in situ mechanical properties of non-selected recycled aggregates from building demolition waste. They used this waste as an unbound aggregate for the base and sub-base layer of the pavement. Mechanical performances of the road were within acceptable limits. In order to reduce pollution and the burden on landfills, a potential solution could be the recycling of demolition waste for construction material for roads, giving a second life to raw materials.

4.4. Ground Tire Rubber

Several research works have been carried out to utilize ground tire rubber in asphalt pavements. One significant study used ground tire rubber (GTR) produced in Taiwan in the production of stone mastic asphalt (SMA). When the rubber was used, no fiber was needed to stop drain-down. The results in Figure 5 show that at 60 ◦C, the rutting resistance of the samples was better than that of conventional SMA mix [49]. SMA samples were prepared with aggregates with a maximum of 13 mm (SMA 13) and maximum of 19 mm (SMA 19). Researchers have also studied ground tire rubber because of the increase in the number tires being dumped into landfills each day. A recent study indicated that the addition of ground tire rubber in asphalt binder enhanced high-temperature properties Pouranian et al. (2020) investigated environmental concerns with respect to the recycling of crumb rubber in bitumen and found that emissions could be reduced with the use of additives in warm mix asphalt (WMA) [53]. Ding et al. (2019) utilized crumb rubber as the rejuvenator for reclaimed asphalt concrete (RAP) and observed improved low-temperature performances.

4.5. Waste Cooking Oil and Palm Oil Fuel Ash

A common waste product is used cooking oil. Burnt cooking oil is produced in enormous quantities in homes and restaurants. As a result, waste cooking oil management is a concern for the environment. According to study, wastes such as burned cooking oil and palm oil fuel ash can be used in asphalt mix. The binder was compared to clean bitumen after it was changed with waste cooking oil, crumb rubber, and palm oil fuel ash.

(A) Plastic crushing

(B) granules

(C) heating

(D) bitumen formation

Figure 4. Process of making bitumen

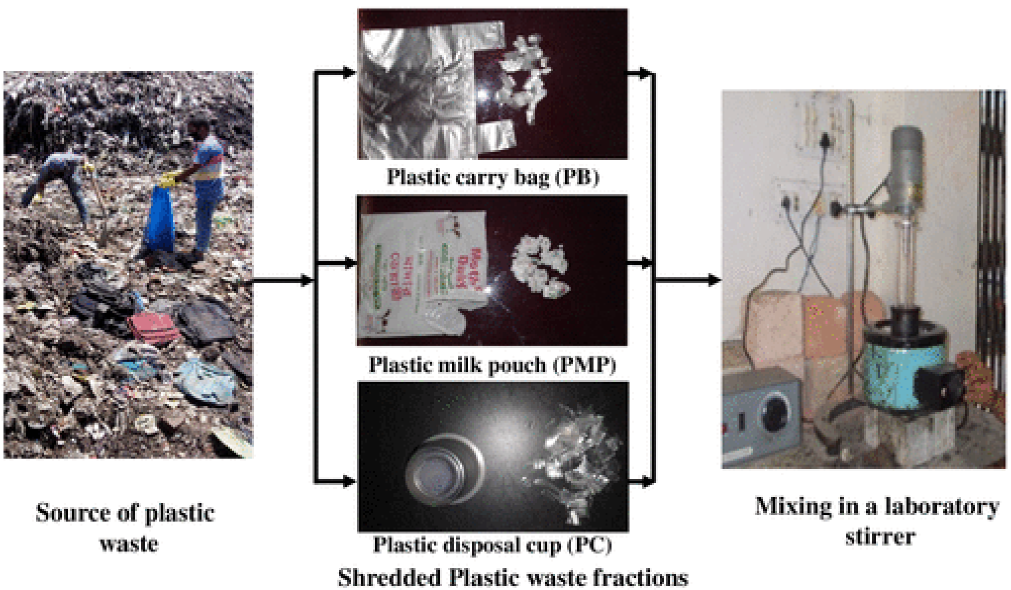

Figure 5. Process of making bitumen

5. MECHANICAL SETUP FOR HEATING PLASTIC

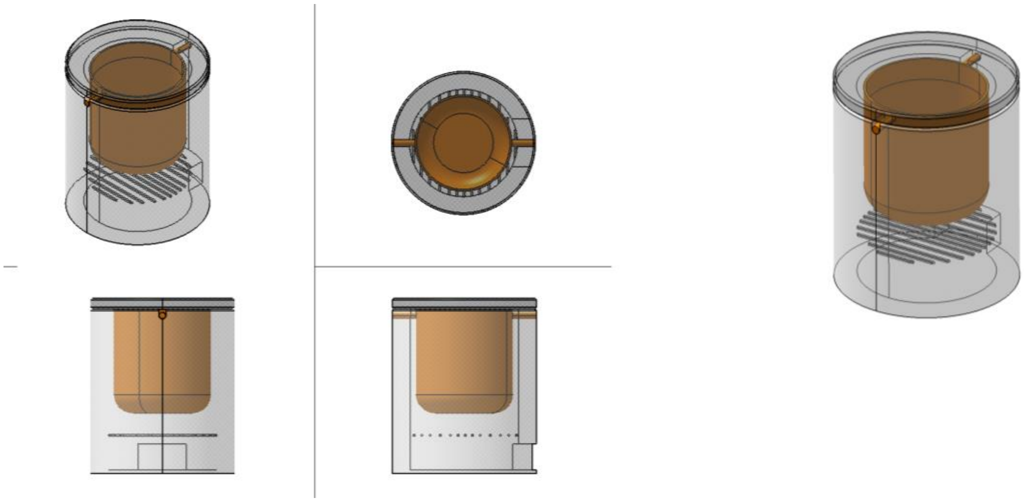

Figure 6. CAD Model

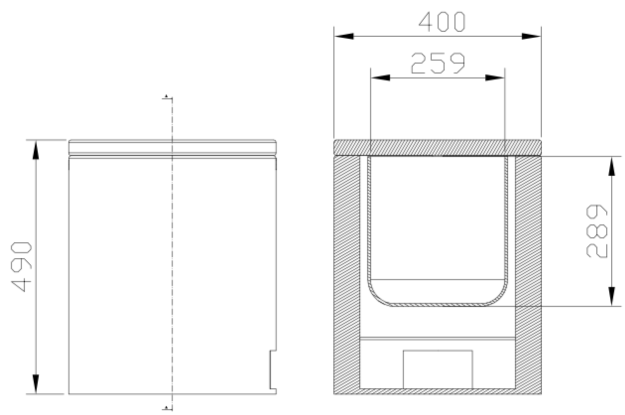

Figure 7. CAD Draft Model

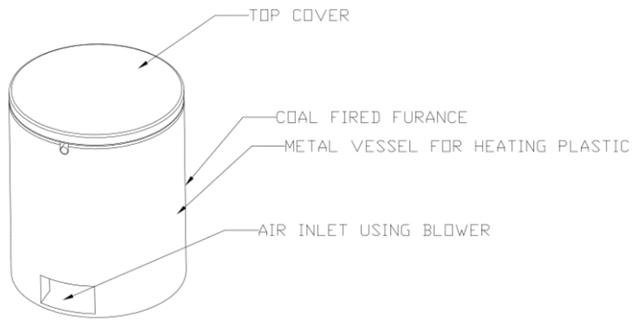

Figure 8. CAD Draft Assembly Model

6. ECONOMICS OF ROAD CONSTRUCTION

Cost analysis assuming cost of plastics waste =Rs 5 per kg.

Cost of bitumen per ton = Rs 50000.

Generally roads in India are constructed in basic width of 3.75m. Consider 1 km length road. To lay 1 km 10 tons of bitumen is required. Cost of bitumen per km =Rs 500000. Assuming optimum percentage of plastic as per the test results of literature reviewed is around 10% (by weight of bitumen). Total quantity of bitumen required = 9 tons. Total quantity of plastic required = 1 ton. Cost of bitumen for 9 tons =Rs 450000, cost of Plastic waste =Rs 5000. Total cost of bitumen and plastic =Rs 455000. Total savings = Rs 45000 per km.

6.1 Advantages

1. Process has generated an additional job for rag pickers.
2. Plastic waste helps increase the strength of the road, reducing road fatigue.
3. These roads have better resistance towards rainwater and cold weather.
4. Since a large amount of plastic waste is required for a small stretch of road, the amount of waste plastic strewn around will definitely reduce.
5. A lightweight prefabricated construction.
6. Faster construction and less maintenance time.
7. Higher quality and a longer lifespan.
8. Little to no maintenance required. The material is virtually impervious to conditions such as the weather and weeds.
9. The innovation is considerably more sustainable.
10. Double use of space. The hollow space in the design can be used to store water or as space for cables and pipes.
11. The possibility of constant safety and water drainage
12. Everything on and around the road can be prefabricate
13. Contribution to the social problem of plastic waste

6.2 Disadvantages

i) Cleaning process- Toxics present in the co-mingled plastic waste would start leakage.
ii) During the road laying process- the presence of chlorine will release noxious HCL gas.
iii) After the road laying- It is opined that the first rain will trigger leaching.

7. RESULT

7.1 Comparison between Ordinary and Waste Plastic Bituminous Road

Sr. No.	Properties	Plastic Roads	Ordinary Road
1	Marshall Stability	More	Less
2	Binding Property	Better	Good
3	Softening Point	Less	More
4	Penetration Value	More	Less
5	Tensile Strength	High	Less
6	Rutting	Less	More
7	Seepage Of Water	No	Yes
8	Durability Of The Roads	Better	Good
9	Pot holes	No	More

- The crushing value reduces from 23.32 to 14.22 for normal and plastic coated aggregate. The value was reduced by 40%. Lower the aggregate crushing value higher is the strength.
- The higher toughness of plastic coated aggregates. Los Angeles abrasion value indicates the hardness of the aggregates. The abrasion value plastic coated aggregates were 21% less than the normal aggregates. · The penetration value of bitumen is higher than the bitumen mixed with the plastic. · The bitumen softens 10oC less than the bitumen replaced with plastic. · The stability of modified bitumen (10% bitumen replaced by plastic) is higher than the normal bitumen.

7.2 Comparison between Normal Roads and Plastic Roads

The durability of the roads laid out with shredded plastic waste is much more compared with roads with asphalt with ordinary mix. Roads laid with plastic waste mix are found to be conventional ones. The binding property of plastic makes the road last longer besides giving added strength to withstand more loads. While a normal highway quality road lasts four to five years it is claimed that plastic bitumen roads can last up to 10 years. Rainwater will not seep through because of the plastic in the tar. So, this technology will result in lesser road repairs. And as each km of road with an average width requires over two tons of polyline, using plastic will help reduce non-biodegradable waste. Plastic roads would be a boon for India’s hot and extremely humid climate, where temperatures frequently cross 500C and torrential rains create havoc, leaving most of the roads with big potholes. The government is keen on encouraging the setting up of small plants for mixing waste plastic and bitumen road construction. It is hoped that in near future we will have strong, durable and ecofriendly roads which will relieve the earth from all type of plastic waste.

8. CONCLUSION

The use of recycled waste plastic in pavement asphalt represents a valuable outlet for such materials. In dry process, the aggregate is modified by coating with polymers and producing new modified raw materials for flexible pavements. Patent has been obtained for this process. Coating of polymers on the surface of the aggregate has resulted in many advantages and ultimately helps to improve the quality of flexible pavement. The coating of plastics over aggregate also improves the quality of aggregate. The use of waste plastic in bitumen helps in substantially improving the Marshall Stability value, strength, fatigue life and other desirable properties of bituminous mix, resulting which improves longevity and pavement performance with marginal saving in bitumen usage. The process in environment friendly.

In addition to the improvement of the quality of the road, this technology has helped to use the waste plastics obtained from domestic and industrial packing materials. This has already been accepted by the Central Pollution Control Board, New Delhi. They have already released a guideline on the technique of the road laying by dry process and its advantage. By this technique, which is in-situ, waste polymer like carry bags, foam, laminated sheets, cups are all used for road laying. Moreover, the use of polymers helps to reduce equivalent quantity of bitumen, thus reducing the cost of road laying. The process thus helps to -

1) Reduce the need for bitumen by around 10%.
2) Add values to plastics.
3) Increase the strength and performance of the road. Carry the process in-situ. Avoid industrial involvement.
4) Develop a technology that is eco-friendly.

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