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Preparation of polymer-coated aggregate by utilization of waste plastic for pavement of roads

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Pakistan, being an underdeveloped country, is highly facing waste disposal and especially waste plastic which lasts for hundreds of years without degradation. Many factors may be involved in it, but we need to purpose and try to urgently implement a constructive idea of using this non-biodegradable waste. The contaminated rain or sewage water and the potholes are the great problems in trafficking and shipping. The idea of preparation of polymer coated aggregate (PCA) is not new, but for our country, it is a whole new process. This study is the country's contribution that is proposing and building not even the idea but the whole process for utilizing the waste plastic in preparation of PCA, which will further be used as road construction material. This study aims at the most suitable solution to these problems, as it was aligned to solve both problems related to the waste plastic and the deteriorated roads, which simultaneously manages waste and improves the road life. The coating of molten plastic over the aggregate supports to recover the value of the aggregate. The binding strength of 290 tons is achieved by 25 wt. % polyethylene while higher binding strength can be achieved by using different plastics. Higher plastic weightage leads to lower moisture absorption, less voids, better soundness and impact value. At the same time, abrasion value is also lowered by higher plastic content thus causing lower friction and skidding of automobiles.

Keywords: Non-biodegradable; waste plastic; polymer-coated aggregate; bitumen; binding strength.

INTRODUCTION

Due to the increased use of plastic and modernization of the world, humans cannot protect themselves from vanishing plastic, so it has to be used constructively. Waste plastic disposal is a major problem of our environment, causing drastic damage to all habitats and increasing pollution, global warming, and is a threat to the existing and the future life. It should be recycled or reused to prevent everyone from all of its hazards. Many ideas have been proposed yet, related to reusing, recycling, pyrolysis of waste plastic, but our idea of using the waste plastic for preparation of road material shall help us to provide better binding property and increased road life. Many researchers have worked on it, and this idea has been adopted successfully throughout the world. Many countries are paving their roads by using their trash, and this is not only an economic way, but it also adds beauty to their environment, supporting tourism and ultimately supporting their economy [1, 2].

A material, which is made from many small monomers having large molecular weights, can be shaped into various things called organic polymer or plastics. Plastics are strong, durable, and degrade very slowly. They are made up of long-chained molecules (polymers) containing repeated units of carbon atoms (monomers). These polymers have extremely strong intermolecular carbon-carbon bonds. If plastic is durable on the one hand, then, on the other hand, it is resistant to degradation [2, 3].

Transportation is one of the most important factors that contribute a lot to the development of a country. As regards transportation, the flexible pavement is very important in constructing roads by using polymer coated aggregate (PCA). It can achieve all requirements of strength, durability, flexibleness, and cost-effectiveness.

This study is based on the usage of waste plastic in an innovative way to prepare road construction material. By adding the waste plastic polymer over the hot aggregate; which will eventually get coated on continuous agitation yielding the PCA, it is further used in the preparation of road construction material by mixing the PCA with heated molten bitumen [1, 4].

In 1907 the advancement of Bakelite accomplished a boom in materials by bringing designed plastic into world trade. Before the completion of the 20th century, plastics were found to be persevering polluters of various ecological fortes, from Mount Everest to the sea level. On

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account of being mistaken for food by animals, flooding low-lying areas by plugging up squander systems, or causing immense revile, plastics have pulled in growing thought as a tremendous poison [2, 5].

Plastic is a polymeric material, that is, a material whose particles are huge, often taking after long ties containing an unending course of action of interconnected associations. For instance, silk exists in abundance, yet nature's "plastics" have not been entangled in environmental tainting since they don't continue on the Earth. Since fabricated plastics are, for the most part, non-biodegradable, they will, by and large, pollute natural surroundings. Likewise, various lightweight single-use plastic things and packaging materials, which speak to around half of all plastics made, are not put away in compartments for the following departure to landfills, reusing centers, or incinerators. They may be improperly disposed of at or near the territory where they end their comfort to the buyer. Dropped on the ground, removed from a vehicle window, heaped onto a successfully full garbage holder, or unexpectedly took away by a tornado, they immediately begin to defile the Earth. Unquestionably, scenes littered with plastic packaging have gotten ordinary in various bits of the world [6, 7].

Materials utilized in the principal half of the twentieth century, for example, glass, iron, aluminum, paper, and plastics have a low recuperation rate. They are generally wasteful to recycle as reused scrap in the assembling cycle, because of noteworthy preparing troubles, for example, a low softening point, which keeps toxins from being driven off during warming and reusing. Most reused plastics are financed underneath the expense of crude materials by different store plans, or government guidelines just commanding their reusing. Reusing rates change drastically from nation to nation, with nations getting rates more prominent than 50%. Regardless, reusing doesn't generally address plastic contamination since reused plastic is "appropriately" discarded, while plastic contamination originates from inappropriate removal [8].

With the increase of advancement and the role of technology in the daily life of humans, polymer plastics have played an important role in facilitating us in every aspect of life. They had taken over the place of metals, ceramics, wood, and all other materials used before, which were far more hygienic and easy to dispose of or reuse than plastic. As time passes, it has become crucial to find robust, long-lasting, and economic way to dispose of or innovatively reuse plastic waste. Several researchers worked on it for a long time and proposed different processes for constructively reusing plastic. Our country is facing the same plastic disposal problem since the start of its use.

Despite being nonnutritive and unappetizing, plastics have defilements up to multiple times. They enter the seawater and a while later pass on to the species that ingest them. In one assessment, levels of polychlorinated biphenyl (PCB), a salve, and ensuring material that is right now commonly precluded, seemed to have extended essentially in the dress organ oil of streaked shearwaters after seabirds had been dealt with plastic pellets winnowed from Tokyo Bay for simply a solitary week [1, 3].

Plastic Contamination Break Down into Microplastic

Afloat, sunlight, wind, and wave action separate plastic waste into little particles, routinely short of one-fifth of an inch over. These alleged microplastics are spread all through the water section and found in each edge of the globe, from Mount Everest, the most raised top, to the Mariana Trench, the most significant box [9].

Microplastics are further disintegrated into tinier and humbler pieces. Plastic microfibers, at that point, have been found in metropolitan drinking water structures and coasting through the air. Sunlight and seawater embrittle plastic, and the conceivable breakdown of greater articles into microplastics makes plastic available to zooplankton and other marine animals.

Plastics changed prescription with life-saving contraptions, made space travel possible, helped vehicles and planes—saving fuel and tainting—and saved carries on with defensive covers, incubators, and equipment for clean drinking water [9, 10].

The facilities plastics offer, regardless, provoked a disposable culture that reveals the material's obfuscated side today; single-use plastics speak to 40% of the plastic made every year. A critical number of these things, for instance, plastic sacks and food covers, have a future of just minutes to hours, yet they may proceed in nature for a long time.

A huge part of the plastic waste is found in the oceans, Earth's last sink, streams from land. Deny is furthermore passed on to the sea by noteworthy streams, which go about as transport lines, getting progressively more garbage as they move downstream. When uncontrolled, a huge aspect of the plastic junk remains in waterfront waters. Nevertheless, when found a workable pace in ocean streams, it might be delivered all over.

The arrangement is to keep plastic waste from entering waterways and oceans in any case. It could be refined with improved waste administration frameworks and reusing a better item plan that considers the short existence of dispensable bundling and a decrease in the assembling of pointless single-use plastics. The second major problem of concern is deteriorated roads, showing poor management and a lack of technology [11, 12].

This research aligned these two major problems by using plastic waste in the production of polymer-coated aggregate (PCA) for road construction material to solve two major problems in a combination, to contribute towards the betterment of society. With the increasing use of plastic, the problems increased, not only related to human health, but due to its toxicity, also related to the environment and all-natural habitats. Humans have troubled not only their lives but also disturbed all creatures. The waste plastic disposed of in oceans is deadly, harming marine life and disturbing the food chain.

Fig. 1. Contamination of waste, mainly plastic, in a local area

The biggest problem for developing countries is the management of solid waste, as shown in Figure 1. Today Pakistan produces about 87,000 tons of solid waste every day, estimated up to 48.5 million tons of solid waste every year. So, it is a matter of great concern because the death rate is increasing due to waste-related diseases, and it causes serious environmental effects. Only a little waste is recycled. Out of 48.5 million tons of solid waste, plastic waste is about 9% of the total waste produced in Pakistan. Because of its non-biodegradability, it produced water stagnation and was associated with hygienic problems [12, 13].

Deterioration of Roads

According to a report by the Permanent International Association of Road Congress (PIARC) and National Highway Authority (NHA), the total length of roads in the country is 264,401 km long Highway network - that is 3.65 % of the total road network carrying 80 percent of the total traffic of Pakistan. Over the past decade, road traffic, including both passengers and freight, has significantly promoted the national economy. Currently, it is 91 percent of national passenger traffic and 96 percent of the cargo. Roadways, highways, and even pathways in Pakistan are generally in very poor condition. The distresses like rutting and fatigue cracking have degraded the condition of the available roads and the current heavy rain makes transportation more unsafe and dangerous for travelers.

(a) (b)

Fig. 2. (a) Small potholes, deterioration of the road (b) Large pothole (contamination resulting in water)

Pavement conditions suggested that 41% of the National Highway (NHA) lost its structural coherence and load-bearing capacity. 58% of the NHA network is suffering from rutting that is affecting transportation and traveler's safety. Nearly 27% of the NHA network has a serious safety hazard where the wheel path ruts more than 25 mm. Even on a smaller scale, the condition of roads is very poor, the potholes and stagnate rain or sewage water are always a trouble for the countrymen, as shown in Figure 2 (a, b) [1, 8].

The major objectives of this research are to recycle plastic waste by reusing it by coating it over the surface of aggregate, which is further used in road construction material. It can improve durability, flexibility, stability, and economy of the road. Strength characteristics of PCA itself and also with bitumen are studied. The polymer coating reduces the voids and cracks, thus having good resistance towards water stagnation and rainwater. The abrasion, weathering, and pothole formations are also reduced. The purpose is to improve and enhance the properties, including binding strength, penetration value, tensile strength, stripping (potholes) seepage of water, better resistance, Marshall stability value, and check the durability for the pavement of roads.

With the rapid increase in the world population, the demand for such a versatile material could automatically increase. The countries are in dire desire of such ideas and implementation of them, which helps to get rid of problems and this idea of using waste into road construction is like converting the waste into treasure, as facing both problems of increasing waste and the poor condition of roads. The waste plastic is either left on roads or dumped in land or oceans. Both ways are harmful. The contribution of plastic cannot be denied in our daily life; rather, it has to be utilized in a constructive way for the nation's prosperity [10, 14].

This study envisages improvements in these parameters after the preparation of PCA, solid waste management, usage of unwanted trash, reducing voids and potholes formation, moisture absorption, and improving cost-effectiveness, compression strength, binding strength. Plastic waste could be classified in several ways, but most often by its physical properties. Based on chemical sources, general groups of plastics are cellulose plastics, protein plastics, natural resin, elastomers, and synthetic resin plastic fibers. According to physical properties, plastic is of two types: thermoplastics and thermosetting plastic.

Upon application of heat, the thermoplastics could be molded into different shapes and become solid on cooling. Common examples are polyethylene, polypropylene, polystyrene, polyvinyl chloride, Teflon, and nylon.

Thermosetting plastics, when once shaped, could not be softened or remolded on the application of heat. Common examples are Bakelite, epoxy resins, polyesters, and polyurethane. According to the property of remolding on heat application, we are using thermoplastics as waste plastic raw material, in our project. Generally, some of the thermoplastics are softened at a temperature of around 130-150°C. It is noticed that at a temperature of around 120-180°C, there is no gas evolution, but beyond this temperature, thermal degradation and gas evolution may occur [6, 15].

Sources of generation of waste plastic are HDPE and LDPE (carry bags, cosmetic bottles, sacks, milk pouches), polyethylene terephthalate (drinking water bottles), polypropylene (wrappers of biscuits detergents, caps of bottles), polystyrene (yogurt pouches, food trays, egg boxes) and polyvinyl chloride (pipes, building, and constructions, electrical fittings).

The waste plastic polymer exhibits good binding properties. When coating the aggregate with molten waste plastic polymer, it will cover the surface of the aggregate. The required PCA is already there. Adding molten bitumen to it will provide a road construction material, whose properties have been improved from the conventional road construction material. The voids will have been filled, and the binding will also have been strengthened, as the molten plastic will cover the surface of the aggregate, that is, attached to it completely, and afterward, this mixture is covered by bitumen. This result will further be confirmed by several testings [3, 12].

To resist the drastic weather conditions and the friction between wheels and roads, the surface layers of pavement may contain the strongest and most expensive material as it is necessary to build roads which have high strength. Roads must have the ability to drain off the surface water, which is the requirement to improve road life, and it is important for vehicle safety also. Asphalt performance strongly depends upon the polymer-coated aggregate.

METHODOLOGY

The basic raw material utilized for this research is easily and cheaply available. Raw materials for lab or commercial basis synthesis are waste plastic (polyethylene, polypropylene, polystyrene), aggregate, and bitumen. In this research, the raw materials for lab and commercial basis synthesis were the same.

The product was obtained in two stages. In the first stage, the waste plastic was melted and coated over the aggregate in the reactor yielding the PCA. In the second stage, the raw material bitumen was mixed with PCA to obtain the final product (the actual road laying material).

Plastic is easily accessed and useful material on the one hand, but on the other hand, it is one of the world's greatest environmental problems. Yet, both society and the industrial sector are highly dependent on plastic. Since it is lightweight, a good insulator and resistant to corrosion, so vast use is undeniable in every sector. Due to its vast use, kinds of research have been made and are in progress to overcome its waste-causing pollution. Scientists are switching towards biodegradable bioplastic made from renewable biomasses or agricultural byproducts. Still, it will take our country, a whole century or more, to shift towards it, and before, we have to reduce our present plastic waste in a useful way, for which our project will play a key role.

Aggregate mainly comprises a broad category of coarse to medium-grained materials. This study uses crushed stones mixed with sand as an aggregate. Bitumen is a highly viscous liquid and a mixture of various products whose main constituent is carbon. For transportation of bitumen through pipes, it must be heated or diluted with a lighter oil. For paving the roads and roofing tiles, far more refined bitumen is used. Desirable properties of bitumen include good adhesion and cohesion. It is water repellant. Its nature is thermoplastic. Drawbacks include oxidation that may occur, which leads to cracks. Water absorption may cause potholes formation. Bitumen is a petroleum product, so its cost is high [13, 16].

This work emphasizes preparing a material that will be used in road construction. It has improved strength than conventional roads, lower water absorption due to lesser voids, lower abrasion between tires and roads, improved life of both tires and the road, and lesser cracks due to better binding.

The selection of appropriate raw materials is the key to achieving the desired product. This project uses a pre-processed raw material (crushed aggregate), and before use, no further processing is required except the waste plastic, which is shredded manually before its use. All the raw materials can be easily stored in atmospheric conditions. The handling of materials can be done properly as the process is done at a high temperature.

This process is an innovative way to find the solution of increasing waste plastic and utilizing it in paving the roads. The prepared PCA is the raw product for road construction material. The heated bitumen is added after the preparation of our desired PCA. We have done some amendments like varying the properties of PCA by varying temperature. This research designs equipment that can bear high temperatures and will also give good mixing for the required product.

Process Description

There is only one process available to prepare PCA that has been adopted. The process is the same as the conventional road construction material process. Still, the modification did find the optimum condition for the best PCA. A new innovative method was proposed by coating waste plastic over the hot aggregate and mixing it with molten bitumen to get the desired high-strength road construction material by designing the reactor to achieve the required temperature and agitating condition. After the preparation of the sample, it will be exposed to different tests to check different parameters. Before starting the actual process, some pretreatments are to be carried to achieve the desired results of PCA.

Segregation

The waste plastic is collected from numerous sources, and non-organic waste is separated from it (if any). For this study, the waste plastic was collected from homes. Later, it will be collected from the neighborhood to initiate the constructive use of waste plastic. For further requirements, it can be bought from the scrap market.

Shredding of Waste Plastic

The waste plastic collected is shredded into small pieces to avoid lumping, so uniform coating will be achieved. Shred the plastic manually in small pieces by using a scissor. The pieces were not single-sized, but this will not cause any trouble as at high temperature it will steadily coat if provided appropriate mixing.

Crushing of Aggregate

The stone aggregate used for road construction was crushed to get a uniformly sized aggregate, so uniform heating and coating will be done simultaneously. For this research, crushed stone aggregate was bought. The plastic waste collected consisted of shoppers, plastic bottles, discarded disposable utensils. We are innovatively using this waste plastic. It was shredded and mixed with hot aggregate, quickly melted and got coated over the hot aggregate. The bitumen was heated separately and was subsequently mixed with this coated aggregate.

Preparation of Polymer-Coated Aggregate (PCA)

The aggregate has to be heated to the highest temperature of nearly 200°C (just to soften the plastic and not decomposing it, to prevent degradation of plastic which causes a great hazard to the environment by producing toxic gases). The shredded waste plastic was added over the heated aggregate with continuous agitation to give a uniform coating of molten polymer. The plastic was softened on heating and coated over the aggregate (monitoring of temperature is crucial). Within a few seconds or a minute, plastic melts and gets coated over the hot aggregate, so PCA is obtained. Plastic gives an oily look to the aggregate and, ultimately, to the PCA. Molten bitumen is mixed with PCA, and the resulting PCA-bitumen mix is ready to pave a road, as shown in Figure 3. The temperature and agitation must be controlled and monitored continuously to achieve the best strength, quality, and durability.

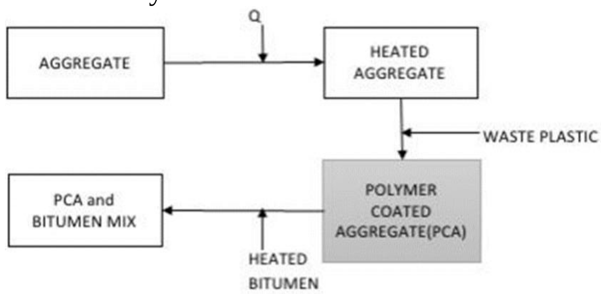

Fig. 3. Bitumen flow diagram for preparation of road construction material through PCA.

Equipment Design

The equipment used for this experiment was not previously available. The prime functions required for PCA are temperature controlling and continuous agitation, for which a heating and mixing chamber was designed as displayed in Figure 4. The non-reactive heating and mixing chamber includes the components shown in Figure 4.

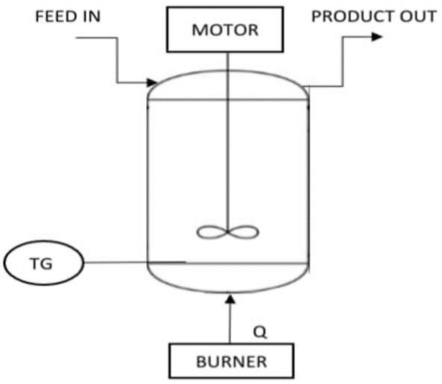

Fig. 4. Process instrumentation diagram for designed equipment.

Vessel. This equipment mainly consists of a vessel in which the raw material is mixed and heated. It is a combination of heater and mixer as required for the simultaneous heating and mixing of polymer and aggregate.

Agitator. The agitator is used for continuous mixing to achieve homogeneous heat transfer and uniform coating of the molten polymer over the hot aggregate. For this purpose, a curved blade turbine impeller is used.

Temperature gauge. As temperature control is the main factor in the preparation of PCA, a temperature gauge is used to observe the temperature readings of the sample. It is placed on the wall of the chamber.

Burner. To provide heat in the vessel's base. The burner is used as a heating source, and the flame is controlled manually for PCA temperature.

Electric Motor. A high-power motor is used to rotate the agitator. As solid raw materials are used, so the motor must be powered enough to continually agitate the mix.

Lid. A lid is used to cover the vessel having a motor mounted on it and the shaft of the agitator fixed in it.

Designed Parameters

Figure 5 (a) shows the designed equipment to achieve that desired product has these designed parameters: minimum required reaction temperature (T) = 100°C; the desired temperature is between 100°C -200°C; material is stainless steel, diameter d ≈ 0.45 m, height ≈ 0.75 m, and impeller = curved blade turbine.

Initially, pre-designed equipment was used, which can do simultaneous heating and mixing, as shown in Figure 5 (b). This pre-designed equipment consists of a closed chamber, insulation of glass wool, impeller, lid mounted with an electric motor, heater rod attached to the lid, temperature sensors, and speed controller for the impeller, mainframe where the reactor and control panel are mounted. A control panel is attached to the reactor to control the temperature and speed of the impeller.

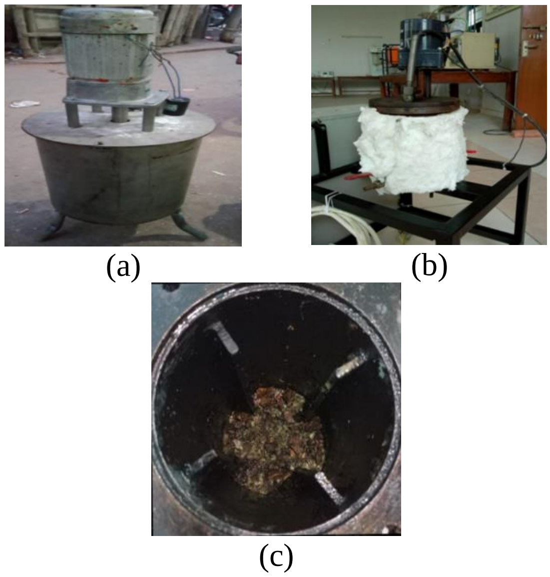

Fig. 5. (a) Newly design equipment (b) Setup of the pre-designed equipment (c) Experimental result (stuck product in pre-design equipment)

While experimenting with this designed equipment, the following observations were made: maximum reaction temperature (T) = 800 ^{o}C; the desired temperature is within this range, volume (V) =2 L, D = 0.108 m, impeller = 45’ tilted pitched blade turbine - 4 blades. This equipment was designed for liquids and had to be modified for the required reactor. During the experiment, the temperature range was appropriate but faced problems and troubleshooting while using this equipment. The capacity of the reactor was too small; also, the diameter was small. The melting rate of the polymer was too slow due to a single heater rod, which results in inappropriate heat transfer - lumps of the molten polymer formed owing to inappropriate heating and mixing due to small blades. As a result, choking of PCA happened after processing, which was cleaned by us but will be difficult in the future as it was a time-consuming process, especially for a reactor having a small opening. Figure 5 (c) shows the stuck product in the pre-design equipment.

Open Flame Process

Figure 6 (a) displays the open flame process, a trial process for the preparation of PCA before designing our equipment. The objective of this open-flame process was to check the melting property and the binding strength of waste plastic while achieving the desired temperature.

Fig. 6. (a) Open flame setup; (b) PCA and bitumen mix in the process; (c) Product of open flame process (d) Block of PCA-bitumen mix prepared in the newly designed equipment

The open flame equipment consists of a circular cooking pot, simultaneously heating and mixing aggregate and polymer. The heating source was the wood logs confined in bricks, and an open stove was used. Two heating sources were made to heat the polymer-aggregate mix and bitumen separately. A large porous cooking spoon was used as a spatula, and a steel container was used for heating bitumen. The thermometer was used to note temperature manually from time to time. Raw materials were the same as defined above. Small mold was used for molding the finished product, as given in Figure 6 (b) to place the cooking pot on the heating source. Add aggregate to the cooking pot and start heating. Check the temperature of the cooking pot using a thermometer; when the desired temperature is achieved, add shredded waste plastic over hot aggregate. It takes a minute to melt the waste plastic and to coat it over the aggregate. Use a spatula to mix the aggregate and the melted plastics for uniform distribution. Add some more plastic; mix it uniformly using the spatula. Heat the bitumen to melt it in the container to about 160°C as hot bitumen has to be added over the hot aggregate for better binding. Then add the melted bitumen over the polymer-coated aggregate to obtain the final product – a uniform mix of the bitumen and the PCA as shown in Figure 6 (c). Put the sample in a mold. Compress it using some weights and wait to get it dry.

While experimenting with open flame equipment, the problem faced was the uncontrolled temperature, as logs surrounded by bricks were used as heating source. The fluctuating direction of the wind was disturbing the flame. One sample was prepared by this method. By observing the failure of achieving the desired temperature and binding, it worked on the fabrication of our equipment to get a better sample of PCA. The newly developed reactor consists of an assembly having the following components:

Reactor (cylindrical vessel made up of stainless steel) designed for heating aggregate and polymer and mixing them simultaneously. *Lid* with a mounted electrical motor. *Impeller* fitted in the lid, its rod attached to the motor used to mix PCA electrically. The heating source (gas stove) is placed under a cylinder as an external heating source. A gas cylinder is connected to the heating source as a fuel source. An open flame process was used for heating and mixing bitumen with PCA. Place the heating source under the reactor and turn it on. Add aggregate in the reactor and start heating on high flame. Add plastic after some time and let aggregate and plastic heat and mix till the plastic is uniformly coated over aggregate using continuous mixing. Check the temperature of the cooking pot using a thermometer; when the desired temperature is achieved, add shredded waste plastic over hot aggregate. It takes a few minutes to melt the waste plastic and to coat it over aggregate. Heat the bitumen to melt to a temperature of about 160°C. Put the sample in a mold. Compress it using some weights and wait to get it dry, as shown in Figure 6 (d).

The sample prepared in this reactor had the following composition: aggregate = 799.6 g, bitumen = 252.6 g, plastic = 140.4 g. It is 9.36% of the total sample, and the remaining from 1500 g was sand that is 307.4 g. Table 1 shows different temperatures and plastic percentages for the various samples.

Table 1. Different temperatures and plastic percentages for various samples

Temperature (°C)	Polymer wt.%	Temperature (°C)	Polymer wt.%	Temperature (°C)	Polymer wt.%
130	2	140	2	150	2
	5		5		5
	10		10		10
135	2	145	2	155	2
	5		5		5
	10		10		10

While experimenting with the newly designed reactor, the following problems were faced: the temperature was slightly deviating from the desired value as it was controlled manually. The fluctuating direction of the wind was disturbing the flame. Electrical heating will give accurate temperature and will be unaffected by wind direction, but it is not economic to use. Due to the mounted motor, the lid becomes too heavy, has to be removed for inlet/outlet of material and to check uniform coating of polymer over aggregate. A small inlet must be designed in the lid that prevents the removal of the whole lid. This study prepared only one sample of this reactor at T = 120°C and 9.36 wt. % polymer (by wt. % of the total sample). The thermal characteristics of the polymer used are given in Table 1. The softening point test is done through ball and ring equipment.

Characteristics of Polymer-Coated Aggregate (PCA)

The main product of this research, PCA, was characterized by property tests.

Binding Strength. The molded block of PCA is subjected to compression by a universal testing machine to check the binding strength of the sample. The addition of plastic in aggregate improves the binding strength of the material [17].

Moisture Absorption. A known amount of PCA block is placed in water for 24 hours and weighed after taking it out. The amount of water absorbed is found by subtracting the mass before and after the immersion of PCA in water. The difference will be the mass of water absorbed. It is expected to realize that the water absorption had been reduced by improving the arrangement, covering plastic over the hot aggregate. This coating of plastic shows a decrement in voids. Therefore, the coating of molten plastic over aggregate supports to recover the aggregate value [17, 18].

Soundness Test. A soundness test is done for checking the protection of aggregate to withstand action. The low-value aggregate causes weight loss. The plastic-coated aggregate is expected to present no or low amount of weight loss, thus approving the enhancement in aggregate value. The soundness directly depends upon the amount of porosity and voids of the aggregate that is decreased by the addition of polymer. It is determined by doing an enhanced weathering test cycle. The net loss in aggregate weight for five cycles must not exceed 12 %, tested with sodium sulfate.

Aggregate Impact Test. Here, resistance or durability of the aggregate is determined to break under rehashed impacts. The total was exposed to 15 blows with a mallet of weight fourteen kg, and the squashed total was sieved on a 2.26 mm sifter. The total effect esteem is the proportion of fines (going through the 2.36 mm strainer size) to the complete load of the example in percent. The aggregate effect esteem must not surpass 30% for its application in asphalts.

Los Angeles Abrasion Test. The repeated motion of the vehicle with a rubber tire will have specific wear and tear done by the external surface of the pavement. For the Los Angeles abrasion (LAR) test, a PCA sample that remained on the 1.70 mm (No. 12) sieve is placed in a huge rotating drum which includes a shelf plate attached to the outer wall of the drum. A detailed amount of steel spheres was then placed in the machine, and the drum was revolved for 500 revolutions at a speed of 30 - 33 rpm. The solid material was taken out and separated from the material passing through the 1.70 mm (No. 12) sieve. The weight of remained material (bigger elements) was then compared to the actual sample weight. The difference in weight was stated as a percent of the original weight and called the percentage loss. For pavements, the LAR value must be less than 30%. The LAR values were less for PCA than for the plain aggregate.

Characteristics of the PCA-Bitumen Mix

Marshall Stability ASTM D 1559. It is the characteristic of the load-bearing capacity of the adjustable pavement of the bituminous PCA at a loading rate of 50.8 mm/min. It is associated with the resistance of bituminous PCA materials to rutting, shearing stress, and displacement.

Bitumen Extraction Test ASTM D2172. The extraction tests are executed as bituminous PCA, mixed with TCE (trichloroethylene), and bitumen separation. Here the separation or extraction of bitumen was almost done. Bituminous PCA was first mixed with TCE, and the mixed bitumen was then extracted, separated, and estimated. The entire elimination of bitumen was not done. A better separation of bitumen was executed using another solvent, such as decalin that also acts as a plastic extractor. The bituminous PCA obtained from step 2 is mixed with decalin for another 30 min, and extracted bitumen was approximated. The extraction was again repeated by refluxing the mix for five min. More separation took place.

Penetration Index Test. This test is done by using a penetrometer. The penetration of a bituminous PCA is the length penetrated in 10 mm. A standard needle would penetrate or enter vertically into a material sample under standard temperature conditions, load applied, and time.

Ductility Index Test. The distance in centimeters determines the ductility of the bituminous PCA material. It can be elongated before fracture when a standard briquette specimen of the material is hauled separately at a definite temperature and speed.

Stripping Test. The stripping value measures the binding strength of the PCA and the bitumen by submerging the mixture in water for 24 h at 40°C. So the water penetrates the pores and voids of the stone resulting in shedding off the bitumen. The outcome results in the release of the aggregate material, and potholes are also formed. The molten polymer that fills the voids of the aggregate also binds the aggregate together and with the bitumen. Now the water does not penetrate over the PCA material, therefore peeling off the bitumen from the PCA stopped and so stripping value enhanced.

Material and Energy Balances

Variables to be used: A = polymer; B = aggregate; 2 = PCA; m = mass flowrate, kg.s^{-1}; x_A = mass fraction of polymer (x_A = 1; as A is pure); x_B = mass fraction of A in B (x_B = 0); T = temperature, °C; $T_A = T_B$ = troom; T_2 = outlet temperature of PCA = temperature of contents of vessel; T_b = temperature of burner; controlled manually; Q = heat added to the system, J.s^{-1} = W; Y = height of mixture (sample) within the vessel, m; V = volume of mixture, m^3; D = mean density of PCA, (mean of density at all stages; at inlet, within the vessel and at outlet of vessel), kg.m^{-3}.

Constants: U = overall heat transfer coefficient, W.m^{-2}.°C^{-1}; A = over all heat transfer area, m^2 and C = specific heat, J.kg^{-1}.°C^{-1}.

The assumptions made while carrying out material and energy balances are: the mixture is non-reactive, perfect mixing takes place; no spatial variations. The density of the polymer is only varying on the application of heat within the vessel and remains constant at the inlet and outlet, assuming constant D. Figure 7 shows the schematic diagram of the designed equipment.

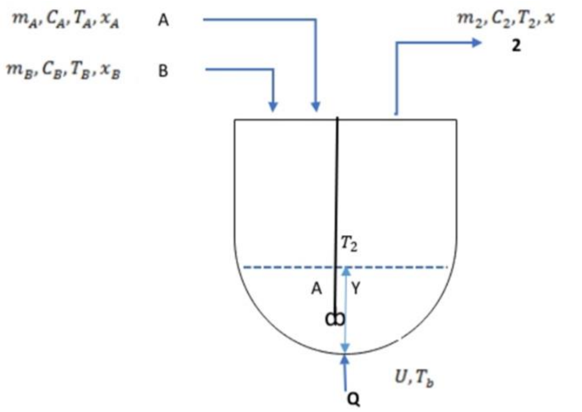

Fig. 7. Schematic diagram of designed equipment

Mass Balance:

Overall balance:

=> $\frac{d(DV)}{dt} = m_A + m_B - m_2$

=> $\frac{D\, d(V)}{dt} = m_A + m_B - m_2$

Since, V = A*Y

=> $D * A \frac{dY}{dt} = m_A + m_B - m_2$

=> $\frac{dY}{dt} = \frac{m_A + m_B - m_2}{D*A}$ .... (1)

Component balance:

=> $\frac{d(D*V*x)}{dt} = m_A * x_A + m_B * x_B - m_2 * x$

Since, x_A = 1 and x_B = 0

=> $\frac{d(D*V*x)}{dt} = m_A - m_2 * x$

=> $D * x \frac{dV}{dt} + D * V \frac{dx}{dt} = m_A - m_2 * x$

=> $D * V \frac{dx}{dt} = m_A - m_2 * x - D * x \frac{dV}{dt}$

=> $D * A * Y \frac{dx}{dt} = m_A - m_2 * x - D * A * x \frac{dY}{dt}$

Using the value of $\frac{dY}{dt}$ from (1)

=> $D * A * Y \frac{dx}{dt} = m_A - m_2 * x - D * A * x\left(\frac{m_A + m_B - m_2}{D * A}\right)$

=> $D * A * Y \frac{dx}{dt} = m_A - m_2 * x - x(m_A + m_B - m_2)$

=> $D * A * Y \frac{dx}{dt} = m_A - m_2 * x - m_A * x - m_B * x + m_2 * x$

=> $D * A * Y \frac{dx}{dt} = m_A - m_A * x - m_B * x$

=> $D * A * Y \frac{dx}{dt} = m_A(1 - x) - m_B * x$

=> $\frac{dx}{dt} = \frac{m_A(1-x) - m_B * x}{D * A * Y}$ .... (2)

Energy balance:

=> $\frac{d(D*V*C_2*T_2)}{dt} = m * C_A * T_A + m_B * C_B * T_B + Q - m_2 * C_2 * T_2$

=> $D*C_2*A \frac{d(Y*T_2)}{dt} = m_A * C_A * T_A + m_B * C_B * T_B + Q - m_2 * C_2 * T_2$

=> $\frac{d(Y*T_2)}{dt} = \frac{m_A*C_A*T_A + m_B*C_B*T_B + Q - m_2*C_2*T_2}{D*C_2*A}$

=> $Y \frac{dT_2}{dt} + T_2 \frac{dY}{dt} = \frac{m_A*C_A*T_A + m_B*C_B*T_B + Q - m_2*C_2*T_2}{D*C_2*A}$

=> $\frac{dT_2}{dt} + \frac{T_2}{Y} \frac{dY}{dt} = \frac{m_A*C_A*T_A + m_B*C_B*T_B + Q - m_2*C_2*T_2}{D*C_2*A*Y}$

=> $\frac{dT_2}{dt} = \frac{m_A*C_A*T_A + m_B*C_B*T_B + Q - m_2*C_2*T_2}{D*C_2*A*Y} - \frac{T_2}{Y} \frac{dY}{dt}$

Using the value of $\frac{dY}{dt}$ from (1)

=> $\frac{dT_2}{dt} = \frac{m_A*C_A*T_A + m_B*C_B*T_B + Q - m_2*C_2*T_2}{D*C_2*A*Y} - \frac{T_2}{Y} \frac{m_A + m_B - m_2}{D*A}$

=> $\frac{dT_2}{dt} = \frac{m_A*C_A*T_A + m_B*C_B*T_B + Q - m_2*C_2*T_2}{D*C_2*A*Y} - \frac{m_A*T_2 + m_B*T_2 - m_2*T_2}{D*A*Y}$ .... (3)

where:

Q = U*A*($T_b - T_2$)….. .... (4)

Mathematical Modeling

Based on the above-derived equations, the following mathematical model was made as given in Figure 8:

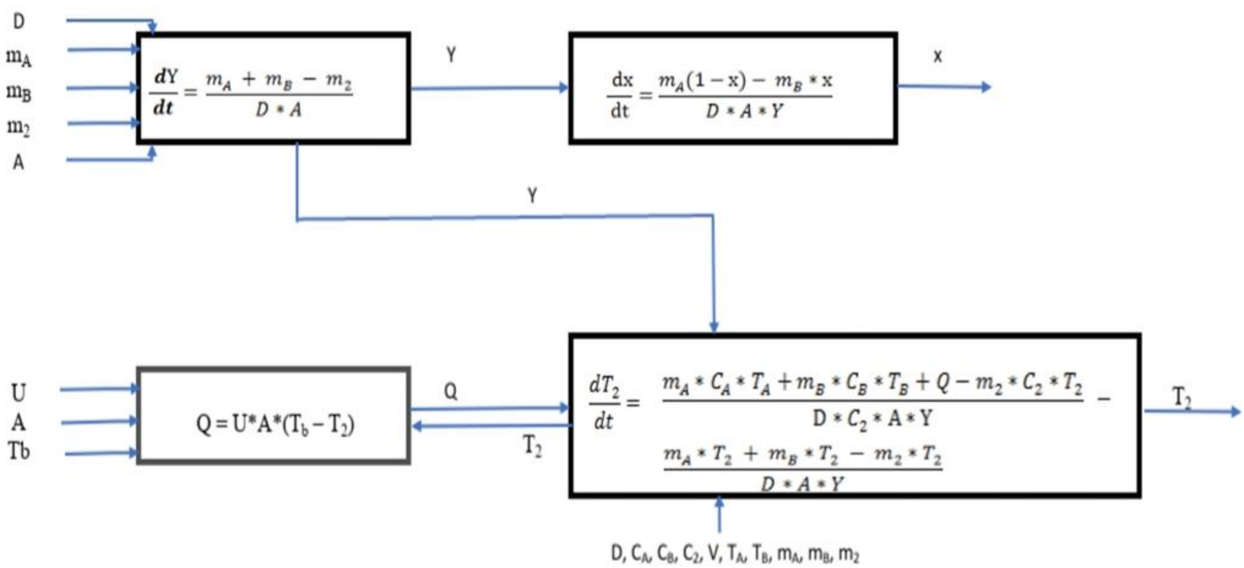

Fig. 8. Derived mathematical model

RESULTS AND DISCUSSION

PCA is an alternative to a bitumen-asphalt mixture and offers great resistance to potholes formation. In PCA, the term aggregate refers to the gravels and sand, while polymer-coated refers to the coating of the gravels by recycled polymers. The data of various test results were taken to support this research to prove the importance of PCA and utilization in the pavement of roads. Table 2 shows the thermal properties of the polymer [18, 19].

Binding strength was tested by varying plastic composition; the maximum binding strength was achieved for the maximum plastic composition, as given in Table 3. The binding strength of 290 tons was achieved by 25 wt. % polyethylene while higher binding strength can be achieved by using different plastics. It was concluded that binding strength is sensitive to the type and composition of the plastic.

Different methods test the physical properties of PCA, and by changing compositions, different results with different physical properties were achieved by altering temperatures and process parameters, as shown in Table 4 [4, 6, 20].

Evolution of harmful gases at different temperatures was tested by varying the temperature and it was concluded that by keeping the temperature below 200°C there is no evolution of toxic gases. Table 5 shows the Marshall stability value for the PCA-bitumen mix [21, 22]. Table 6 shows the results of the bitumen extraction test, and the physical properties of waste plastic are given in Table 7 [14, 17]. Table 8 shows the stripping value of the PCA-bitumen mix. Higher plastic weightage leads to lower moisture absorption, less voids, better soundness and impact value. At the same time, abrasion value is also lowered by higher plastic compositions, which is one of the disadvantages of higher plastic content as lower abrasion value offers lower friction and causes skidding of automobiles.

Table 2. Thermal properties of polymer

Type of polymer	Solubility in water	Softening temperature range (°C)	Products reported	Decomposition temperature range (°C)	Products reported	Ignition temperature range (°C)	Products reported
PE	nil	100-120	no gas	270-350	CH_4, C_2H_6	>700	CO, CO_2
PP	nil	140-160	no gas	270-350	C_2H_6	>700	CO, CO_2

Table 3. Variation in binding strength

Type of polymer	Plastic wt. %	Binding strength (Kg)	Compression strength (Tons)
Polyethylene (PE)	10	325	250
	20	340	270
	25	350	290
Polypropylene (PP)	10	350	280
	20	370	290
	25	385	310

Table 4. Aggregate technical properties

Plastic coated over aggregate wt. %	Moisture absorption %	Soundness %	Aggregate impact value (AIV)	Los Angel's Abrasion/ Rattler test (LAR) %	Voids %
0	4	5±1	25.4	26	4
1	2	Nil	21.20	21	2.2
2	1.1	Nil	18.50	20	1
3	Traces	Nil	17.00	18	Nil

Table 5. Marshall stability value for PCA-bitumen mix

Bitumen wt.%	Polymer bitumen wt. %	Type of polymer plastic	Marshall value (KN)	Flow value (X) (0.25mm)	Void %	Marshall Quotient (KN/mm)
4.5	5	PP	16	4	53	4
4.5	10	PP	20	5	55	4
4.5	10	PE	20	4	58	5
4.5	15	PE	22.5	4	56	5.63

Table 6. Bitumen extraction test

Plastic wt. %	Bitumen extracted after 5 min %	Bitumen extracted after 10 min %	Bitumen extracted after 15 min %
0	96.0	98.0	99.0
0.5	63.5	88.7	92.3
0.75	63.2	86.7	90.7
1.0	61.3	76.7	83.6

Table 7. Physical properties of waste plastic

Commercial plastic material	Nature of plastic	Thickness (microns)	Softening temperature range (°C)
Carry bag	Polyethylene	10	100-120
Cup		150	100-120
Water bottle		210	170-180
Soft drink bottles		210	170-180
Parcel cover		50	100-120
Film		50	120-130

Table 8. Stripping value of PCA-bitumen mix

	Plain aggregate				PCA			
Time (hours)	2	24	72	96	2	24	72	96
Stripping value	0	0	2	5	0	0	0	0

Process Costing and Economic Analysis

This novel strategy for up-degree streets ends up being valuable and practical, sparing millions of rupees. There are enormous prospects of the street up-degree as far as quality and cost-viability, as the condition and nature of streets are declining day by day. Due to increased waste problems and early damage of roads, especially in Karachi, which occurred due to stagnant wastewater or any other reason, the economic sustainability of the city and even the whole country is declining as health and transportation problems are increasing gradually. This method not only provides the utilization of landfilled waste but also contributes towards the improvement of road properties and lowering the cost of road material with durability, thus economically uplifting the country.

Basic Costs: cost of waste plastics = Rs. 25/- per kg, cost of bitumen per drum (200 Kg) = Rs. 8400/- and cost of bitumen per kg. = Rs. 42.00/. Generally, roads are constructed in a basic width of 3.0 m, 3.75 m, and 4.0 m. Consider a 1 km length road of width 3.75 m.

In terms of aggregate: Let optimum amount of waste plastic used = 10% (by wt. of aggregates). Amount of aggregates used in road construction (1 km length × 3.75 m width) = 3750 m^2 × 12.5 kg per m^2 (avg.) = 46875 kg. So, amount of waste plastic used in road (10% by wt.) = 4687.5 kg. Total cost of waste plastic used = 4687.5 * 25 = Rs. 117,187.5/-. Cost of bitumen saved (4687.5 kg equivalent to plastic used) = 4687.5 * 42 = Rs. 196,875/-

In terms of bitumen: let the optimum percentage of plastic in the blend as per different testing results is around 5% wt. of bitumen. Cost of road (new) / kilometer: bitumen required for work (approximately) 21,300 kg per km, cost of bitumen in new work per km= 21,300 * 42 = Rs. 894,600/-, waste plastic coated over hot aggregate for PCA (5% by wt. of bitumen) = 21,300 * 0.05 = 1,065 kg, cost of waste plastic used = 1,065 * 25 = Rs. 26,625/-, cost of bitumen saved (1065 kg equivalent to plastic used) = 1,065 * 42 = Rs. 44,730/- and total savings per km = 44,730 – 26,625 = Rs. 18,105/-

Cost of road (up gradation) / kilometer, bitumen required for work (approximately) = 11,925 kg per km, cost of bitumen in repairs (up gradation) per km = 11925 * 42 = Rs. 500,850/-, waste plastic coated over hot aggregate for PCA (5% by wt. of bitumen) = 11,925 * 0.05 = 596.25 kg, cost of waste plastic used = 596.25 * 25 = Rs. 14,906.25/-, cost of bitumen saved (596.25 kg equivalent to plastic used) = 596.25 * 42 = Rs. 25,042.5/- and total savings per km = 25,042.5 – 14,905.25 = Rs. 10,137.25/-.

Economic Outcomes

All kinds of waste plastic used are most problematic to the environment. The burning of waste plastic produces hazardous gases that can be limited by using plastic in the proposed process. Landfilling will be reduced to a larger extent by utilizing the waste plastic that contributes to a larger portion of solid waste that is increasing day by day. The non-biodegradable plastic covering prevents composting of organic waste, which will decompose more quickly after eliminating plastic. Once the plastic is separated from the organic waste, farmers can directly utilize the latter instead of purchasing fertilizers. The government expenditure will lower on road construction. The increased life of roads will be the most cost-effective and sustainable benefit. The enhanced road properties by the use of non-biodegradable and durable plastic will ease transportation.

CONCLUSION

This constructive method of obtaining PCA and its utilization to prepare road construction material or any other use will become a definite part of the environment. This study was aligned for the solution of the two major problems faced by the country - increasing waste plastic and increasing and early deterioration of roads - through the utilization of waste plastic polymers in preparation of PCA for construction of road material. The preparation of PCA utilizes the waste plastics and reduces them in the future so that the pollution rate will also be decreased and marine life could be saved. The PCA will be one of the economical and beneficial materials for road preparation because it saves 1 km of road material as the shredded plastic in the form of polymer covers the aggregate and occupies a large portion of the road. The absorption rate of PCA is very low due to the utilization of waste plastic. The life of the road will be increased because of its low porosity, and there will be no pothole formation. The addition of waste plastic in aggregate (PCA) will help improve the strength (Marshal stability value) and the durability of the pavement. The water absorption was reduced by improving the arrangement, covering plastic over the hot aggregate. This coating of plastic shows a decrement in voids. The plastic-coated aggregate is expected to present no or low amount of weight loss, thus approving the enhancement in aggregate value. For pavements, the Los Angeles abrasion (LAR) value must be less than 30%, showing better water resistance, no water stagnation, no stripping, and no potholes.

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