Pilot Scale Plant Fabrication for Plastic Coated Aggregate-Based Road Making Material

Ullah, Ahmed
Chemical Engineering Department, NED University of Engineering & Technology, Karachi, Sindh, PAKISTAN

Mushtaq, Asim*+
Polymer and Petrochemical Engineering Department, NED University of Engineering & Technology, Karachi, Sindh, PAKISTAN

Qamar, Rizwan Ahmed; Ali, Zaeem Uddin; Zaidi, Wajeeha; Afshan, Siddiqah; Jamil, Abdul Ala; Ayub, Laiba; Siddiqui, Hafiz Huzaifa
Chemical Engineering Department, NED University of Engineering & Technology, Karachi, Sindh, PAKISTAN

ABSTRACT: *The problem with waste plastic is that it decomposes after hundreds of years which causes its accumulation on the land. The waste plastic is used in the production of Polymer-Coated Aggregate (PCA) material that is eventually used in the construction of commercial roads. The roads made from PCA material are more efficient and are of greater strength as compared to normal roads. Through previous extensive experimental work, it is concluded that the addition of 12% of plastic in the total mixture provides the optimum results. The chosen process for the research to make PCA is the dry process, which follows by heating the aggregate stone to a certain temperature and on the other hand melting the PCA and coating over the aggregate. This research is mainly based on the fabrication of a machine that eventually produces PCA. The process of production of PCA material includes pre-heating crushed aggregate, shredding of plastics, melting and coating of plastics, heating bitumen, adding hot molten bitumen, and uniform mixing. The aggregate tests began with each batch sample from the machine to validate the working and product quality of the fabricated mixer. The mean of Marshall stability value, flow value, and % air void are 2651.893kN, 17, and 2.642% respectively. Whereas the mean aggregate crushing and the impact value obtained is 9.778 and 7.627. The mean value of specific gravity obtained is 2.569. The produced PCA material has a low water absorption capability is 0.573. The Los Angeles abrasion test, 9.652 is the mean abrasion value observed. The mean value of the stripping test obtained is 0.197%, which shows that there is almost negligible stripping of bitumen from the surface of PCA. It can be concluded that the fabricated rotary mixer gives us an adequate PCA product with suitable enhancement of binding properties for the pavement of roads.*

KEYWORDS: *Polymer-coated aggregate; Road material; Aggregate crushing value; Marshall Stability test; Bitumen; Impact test; Moisture absorption Test.*

**To whom correspondence should be addressed.*
+ E-mail: engrasimmushtaq@yahoo.com
1021-9986/2023/9/2977-2991 15/$/6.05

INTRODUCTION

With the passing decades, the usage of plastic has become the norm in our society and the world. The production of plastic has increased extensively, from 2.3 million tons in 1950 to 448 million tons by 2015, this means fifty percent of all the plastic has been manufactured in the last 15 years. Although it's a favorable product, its waste and corollary corruption have made it's dumping an issue for our environment. To make a strategic process for its effective disposal, recycling, and reuse. To engineer a machine for the salvage of waste plastic disposal. As plastics are reliable, durable, lightweight, and cheap materials, they can easily get melted, molded, and used in a plethora of applications. The easiest way of recycling plastic processes includes collecting, rearranging, shredding, washing, melting, and compressing. The current innovative techniques that have been adopted have quite made the recycling process of plastic simpler and more economical. Such technologies comprise reliable detectors and sophisticated decision and recognition software that simultaneously enhance the efficiency and accuracy of sorting out the plastic. But if see the utilization of waste plastic in making the roads ends up helping to improve the environment's sustainability, which will eventually lead to improved permanence and pavement performance [1, 2].

Plastics are durable and degrade gradually, the chemical bonds that plastic has make it durable and equally resistant to the natural phenomenon of degradation. Although, two major categories of plastic are thermoset and thermoplastics. A thermoset is a kind that when heated gets solidified irreversibly. Their strength and durability make them one of a kind, and therefore they are used primarily in the applications of construction and making of automobiles. Some examples are polystyrene, polyethylene, terephthalate, polyamide, and poly-oxy-methylene [3, 4]. The main thrust of the area of today's research work is sustainably using the disposal of plastic. So unwanted plastic generated by various sectors in our society can be an opportune raw material for asphalt pavements. The range of temperatures to melt plastic was generally found to be from 100°C to 130°C [1, 5]. Today's study shows that if plastic waste like polyethylene, polypropylene, and polystyrene is coated with overheated aggregates then PCA material is mixed with bitumen next and this mixture can be used for flexible road pavement construction. The resultant PCA has proved to be a better patching material. Now moving on to the importance of recycling plastic waste and its effective utilization with technical development in the coating of aggregates that are to be used for pavement construction aimed towards improving its physical characteristics. Fig. 1 shows the raveling of the pavement due to asphalt binder ages and edge cracks in roads due to the ingression of the water in underlying layers [6, 7].

Previous literature recommended that aggregates can be replaced by aggregates or could serve as a binder modifier. The thought of removal of plastic and turning it into a useful product would be a great advancement on the Earth. The main aim of this research is the recycling of waste plastic which ended up being used in making the road, the vital objectives of the plot are; to reprocess the plastic by transforming it into an effective material for road construction, by coating it over the surface of aggregate and mixing it with hot bitumen. Fabricate a pilot plant machinery for the making of polymer-coated aggregate material and study the stability, durability, flexibility, and economy of the yielded road material (PCA) from the equipment designed for the research. The mixing of polymer with hot aggregate and molten bitumen will end up improving its strength to a better extent than conventional roads [8, 9].

In this research, fabricate a pilot plant machine to make PCA which will further be dumped on the surface of the broken road, and the patch of PCA will ultimately be ready to mend the deteriorated road. It hopes to expect a good deal of outcome from the machine. There are some areas from which are expecting improvement, once the PCA becomes functional and generated from the pilot plant: the strength and performance of the road get better. The fatigue life of roads will be improved and plastic waste gets the purpose to be useful through its recycling. An eco-friendly technology with a sustainable environment. Poisonous smoke and gases released due to the burning of waste, plastic could be reduced. The flexible pavement of roads will be observed by using the blend of polymer-coated hot aggregate mixed with hot asphalt and the properties will be enhanced by using polymer in road construction; toughness will be improved to resist the fracture caused by jumps of vehicles. Abrasive effects can be borne when the hardness turns high and the strength is high enough to tolerate the load of heavy vehicles.

(a) (b)

Fig. 1: (a) Raveling of the pavement due to asphalt binder ages (b) Edge cracks in roads due to ingression of the water in underlying layers

Water absorption will be lower when voids will decrease with an increasing amount of plastic. Cracks will be not generated due to better binding in the material and abrasion will be reduced between roads and tires.

The raw materials for commercial-based pilot plant/lab testing are plastic waste (polyethylene terephthalate, known as PET), aggregate (crushed stones), and bitumen (molten asphalt). In this study, raw materials used in commercial pilot plants and lab testing are the same, as the product obtained from the machine is exactly going to be tested for checking its purity, properties, and commercial usage. The product that is aiming to obtain comprises two major steps: primarily, the waste shredded plastic pour over the hot aggregate where it melts and coats in the mixer to form polymer-coated aggregate. Secondly, the raw asphalt (bitumen) is poured over and combined with PCA to procure our final material. There have been many research studies and experimental studies done on polymer-coated aggregate. A thorough study on the methodology of using waste plastic in bituminous mixes and various tests has been performed to evaluate the potential of PCA. The main motto of the following tests, research studies, and experiments is to evaluate the performance of PCA to its best utilization and performance. To compare the properties of the regular bituminous mix specimen with polymer-coated aggregates, these are the following test that has been done to differentiate the characteristics of plastic-coated aggregate and the simple bituminous mix aggregate [10, 11].

Mixing procedure at the hot mix plant; plastic waste of PE and PP is shredded into pieces, the aggregate is heated to 1650 °C, bitumen up to 1600°C, and the laying temperature of the mixture is between 110 °C to 1200 °C. At a mini hot mix plant; the same procedure occurs in this machine but with a lesser capacity of produced material. Mixing by Central Mixing Plant (CMP); the same procedure goes in CMP as well, just with a conveyor belt. CMP helps to have much better control over temperature and gives better mixing [12, 13].

The coating of waste plastic improves the quality of the aggregate and its impact value. The addition of plastic helps in producing better toughness of aggregate to face the impacts. The aggregate with lower crushing value (range should be less than 10%) points towards the lower crushed fraction under load and would provide a longer service life to the road. Whereas, the plastic-coated aggregates show a lower crushing value and its range should be less than 30-35%. The specific gravity is an indirect measure of its strength, so plastic-coated aggregate shows the increased specific gravity which is ultimately increasing the strength of PCA. The range should be within 2.5-3.0 %. Stripping value gives the value of moisture upon the adhesion of the bituminous film to the particles of aggregate on the surface. The plastic coating over the aggregate decreases the affinity toward the water. The range should be less than 25%. The aggregate when coated with a polymer made the quality of moisture absorption better. The results proved that the absorption of the aggregate is within the range of IRC specifications that declined to nil because of coating. The range must be less than 10%. This test gives the wear and tear value of repeated movement of vehicles on the road. Under the study of PCA material, the percentage value of wear and tear was found to be declining order with the use of plastic. The test and analysis on aggregate and bitumen were conducted to investigate the properties of aggregate

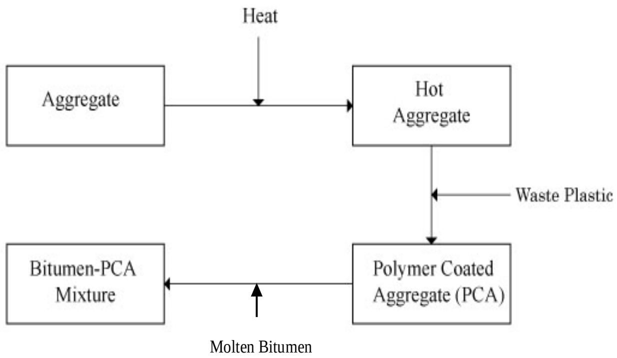

Fig. 2: Process flow diagram for production of PCA

material alone; aggregate impact test, Los Angeles abrasion test, water absorption, specific gravity, and aggregate crushing value. Flakiness and elongation index of aggregate, likely the test on aggregates, bituminous materials had gone through the test include penetration test, ductility test, softening point test, specific gravity test, viscosity test, flash and fire point. After making the PCA material, the previously mentioned tests were also performed. Some pretreatments like segregation, shredding waste plastic, crushing, and sieving of aggregate are done before starting the actual process [14-16].

In order to produce Polymer-Coated Aggregate (PCA) there are two processes available; dry process and wet process. In the dry process, the polymer is first directly added to the bitumen then this mixture is coat over aggregate. Whereas, in the wet process, the polymer is first melted and coated over the aggregate then molten bitumen is added to the aggregate polymer mixture. The chosen process for the research to make PCA is the dry process. In our process of making the PCA from a pilot plant, first, we are going to take 12% plastic composition, which turned out to be the best percentage of waste plastic in the end according to past research. [17, 18]. As this research is mainly based on the fabrication of a machine that eventually produces PCA according to the best research studies by various scientists and scholars. The design of the equipment is selected because it’s a non-reactive heating mixer and manufactured material at its best-desired properties by doing proper mixing and heating [19, 20].

EXPERIMENTAL SECTION

There are different ways of producing the road material however here are using polymer-coated aggregate for the construction of commercial roads. In this process, the hot aggregate is coated with molten polymer gained from waster plastic. Later the polymer-coated aggregate is mixed with molten bitumen. The final product achieved which is road material leads to the construction of roads that are of high strength. Because the polymer present in it melts at a higher temperature as compared to bitumen and also the mixture has the optimum amount of air voids that allows locking a minimum about of moisture in it, at the same is enough to allow the expansion to prevent damage. There are a few steps that need to be performed before starting the actual process to achieve the best form of PCA material, as given in Fig. 2.

Materials

There are different types of plastics presents in the waste which includes HDPE, LDPE, polyethylene terephthalate, polypropylene, polystyrene, polyvinyl chloride, and polyurethane. It is required to segregate each type of plastic so that a selected type is used in the production of PCA material to maintain its consistency. This work uses polyethylene terephthalate (PET) water and soft drink bottles in the production of PCA material. PET is preferred over other plastics is because it possess the highest melting point and it is readily available as a waste. After the segregation of plastics, it needs to be washed properly to avoid the production of any kind of toxins during the process. After ensuring that the plastics are washed and de-dusted, they are then shredded into smaller pieces in a plastic shredder. Shred the plastic to avoid lumping during the process when they are exposed to high temperatures. The smaller pieces of plastic get easily melt and form a uniform layer of polymer over the aggregate. In the production of road material, the stone aggregate of uniform size needs to be crushed to achieve uniform heating and coating of the polymer layer. This project uses an aggregate of about 20 mm mainly. Using the aggregate that is already being crushed but sieving the aggregate to achieve the size uniformity. Plastics in their different types are majorly contributing to the total waste in the environment. The waste plastic of each type is segregated. Any type, in the project, polyethylene terephthalate (PET) is washed, cleaned, and shredded into smaller pieces is sprinkled upon hot aggregate where with continuous mixing and heating is molten and coated upon aggregate. Simultaneously, the bitumen is heated separately and when the PCA material is mixed properly then the hot molten

Fig. 3: Designed equipment for a rotary mixer

bitumen is added to the mixture. After proper mixing, hence the ready-to-use road-making material is achieved.

Preparation and method of Polymer-Coated Aggregate (PCA)

Firstly, all three raw materials are weighted. Because they are required to be added in specified percentages to achieve the optimum results. Add 75% of the crushed aggregate, 13% bitumen, and 12% plastic to the total mixture. Add the weighted aggregate to the rotary mixer to preheat properly around 180ºC to 200°C (only want to soften the plastic and avoid its degradation which could cause a hazardous situation for the environment by adding toxic gases to it). The shredded plastic is added to the mixer which is then melted over the hot aggregate and with continuous mixing the molten plastic is uniformly coated over the aggregate and that's how a dry aggregate is coated by polymer layer. Simultaneously with the mixing, the bitumen is also being heated and when the dark oily PCA material is obtained in the mixer, the hot molten bitumen is added to the mixer. After proper mixing, the bitumen-PCA mixture is achieved and is ready for the construction of roads.

The rotary mixer is the main component of the equipment. It contains some components that include: the roller drum mounted on a trolley. The drum has a capacity of around $20m^3$. It is connected to the motor, a gearbox, and a combination of pulleys. Its design is inspired from the concrete mixer. Necessary addition of components has been made to achieve the aim of uniform mixing and heating. That's why just beneath the rotary mixer, there is a burner as the heating source. Just beneath it, there is a burner as the heating source. Gears are used for the transmission of the power of the motor through pulleys. The actual speed of the motor is much higher than the required speed which is 35-40 rpm. So, a pulley of diameter 16 inch is added to reduce the speed. All the equipment is mounted over the trolley due to which the mobility of the equipment becomes easy and convenient [1, 2, 21, 22]. To rotate the whole rotary mixer along with raw material, a high amount of power is required. A high-power electric motor is used to provide the rotational motion to the rotary mixer. The motor used is 1hp. For providing heating to the mixer a gas burner is used. It is located at the bottom of the rotary mixer. As the mixer rotates, it uniformly provides heat to the overall surface of the mixer. The flame of the burner is being manually controlled by the valve present at the gas transmission line. The wirings of the motor are connected to the control panel. A control panel is added to turn on and off the machine. The designed parameters of the equipment to obtain the desired PCA material are; temperature: 150-200°C, material: mild steel, diameter: 24 inches, depth: 27 inches, and motor: 1hp. Fig. 3 shows the designed equipment of the rotary mixer.

The experimental study to validate the machinery was done to facilitate the proven results of the product. There is a total of seven tests to be performed that would ultimately bring out the originality of the produced material. Primarily, did a setup of the fabricated equipment with the gas-filled cylinder, electric connections for the breaker, and ready raw material to pour in. Started to cook the required material initiating with the burning flames to pre-heat the aggregate and noting down the temperature at about 140°C – 160°C. After heating the aggregates, add the crushed PET bottles into the mixer and turn on the circuit. The sampling phase began with the equipment heating. As soon as the machine started to heat itself, the consequences started to appear because the surrounding of the machine become hot and smoky. After heating the aggregate, the addition of PET bottles accelerated the process. The plastic started melting and coating the aggregate, it was also observed the toxicity in the air that is smell of plastic. The extent of the addition of plastic was adopted from the previous year's project optimum results which are 12% plastic composition (140-150°C) and continued the research with the adoption of the verified proportion of plastic sample [23, 24].

Characterization of PCA

To find out the reliability of the machine and validate the product (plastic coated aggregate) made by it for

Table 1. Reading of marshall stability test sample

Sample	Plastic Composition %	Height-1mm	Height-2 mm	Height-3 mm	Average Height mm
1	12	52.88	52.35	52.69	52.64
2	12	59.09	58.9	59.51	59.16666667
3	12	56.23	56.16	56.43	56.27333333

the best road construction material performed the required seven tests.

Marshall stability test

It is widely performed to find out the plastic deformation of the road paving material. It helps to determine the maximum load supported by the test specimen. A suitable mix will restrict deformation from traffic loads and damage from climatic scenarios. Void Analysis could be performed to estimate the compactness or binding between aggregates and bitumen. ASTM D1559-89 standard test method used for Marshall Stability and flow of asphalt mixtures. Find Marshall Flow values of all the samples, with their air voids percent, and compare the values. To be able to validate the sample extracted from the equipment, to meet the optimum stability and traffic demands while staying within the allowable distortion limit and having the least amount of void in the compacted mix to allow for a small amount of additional compaction under traffic without bleeding while keeping the void low enough to prevent entrance of air and moisture. Specimen mold assembly-mold cylinders are 6 inches in diameter and 3 inches in height, base plates and extension collars, Sample ejector, and compaction hammer. Pedestal with rammer for compaction, specimen mold holder, breaking head, flow meter. Miscellaneous equipment; container steel trowel, spatula, thermometer, gloves ovens or hot plates, water bath. After taking out the batch from the machine, separated the 3 samples of polymer coated aggregate containing 12% PET composition. The steps are shown in the complete test procedure.

Three samples of the hot mixture are being poured layer-wise into the Marshall mold having a collar and base. To prevent the hot mixture from sticking to the base plate, filter paper is placed under and on top of the sample. Carefully place the mold on the compaction pedestal along with a hammer on the compaction assembly to compact the mixture. Compaction is carried out by giving 75 blows from the hammer mold is then turned around and given 75 blows to ensure compaction from both sideways. After compaction, mold is taken out and put out to settle, and left for cooling as shown in Fig. 4. The sample is extracted by using the extractor machine. After extraction, samples are then allowed to cool down for a few hours.

After this, measured dry weight of all three samples one by one. The sample is then submerged in water. This submerged weight is noted to measure the density of the specimen and participate in the calculation of void properties. Firstly, the samples after submerging and weighted, their width are measured via a vernier caliper. After this, the prepared samples are placed in a water bath at 55°C for 40-45 minutes. Samples are then taken out from the water bath, dried properly, and placed in the breaking head. The upper segment of the breaking head is fixed and the complete assembly is placed on the testing machine. The Flow meter is placed over the breaking head and is adjusted to read zero. Load is applied at a rate of 50 mm per minute until the maximum load reading is obtained. Maximum load readings and flow values are recorded simultaneously [21, 25, 26]. After complete steps of testing, the samples are removed from the samples which are a little broken and discarded. The readings observed for the specimen are given in Table 1.

Crushing test

The aggregate crushing value test is used to find out the strength of coarse aggregates and its relative measure to the resistance of an aggregate to crushing undergoing slowly compression load applied. Aggregate crushing value is known as the percentage by weight of the material that is crushed or finer that is obtained when the test aggregates are put out under specific standardized load conditions. Standard code of test is ASTM D5821. The maximum allowable aggregate crushing value is recommended to be a maximum of 45%. The crushing value of aggregates and validating the percentage at standard 12% composition of polymer involved. First collected the aggregates from the pile of coarse aggregates and sieved them in such a way that it passes through a 12.5 mm

Fig. 4: Samples from molds

sieve and retains in a 10 mm sieve. Aggregate is then coated with standard 12% plastic composition by the batch of stones in our mixer. The cooked batch is then taken out and three samples of coated aggregate are separated, then placed layer-wise in the small cylinder and tampered with 25 times. After tampering, it is leveled and weighed after filling. After weighing the sample of PCA, it is transferred to a huge cylinder and again gets tampered with. The cylinder is then placed into the crushing test machine. After the test, a huge cylinder is upturned and samples are taken out in the tray. PCA sample is then again sieved through a small size 2.366 mm sieve. The material passed through the sieve is collected and weighed finally [27, 28].

Impact test

The resistance of instant impact, shock, or load can be determined through the impact value test. The firmness and strength of the aggregates can be examined through this test. Aggregate should be tough enough to resist the grinding action of traffic load [3, 29]. The maximum allowable aggregate impact value AIV is proposed to be 30%. Determine the impact value of aggregates coated with 12% plastic composition and find the suitable impact value to validate the mixer of our equipment that is the lowest AIV value. Standard code of test is ASTM D5874-16. A testing machine weighing around 48-58 kg, has a metal base with a diameter of 12 inch. A supported base of concrete floor consisting of a thickness of around 40-48 cm. Firstly, the required size of aggregate is sieved. Sieved the aggregates passing through a 12.5 mm sieve and retained them on a 10mm sieve.

After sieving the aggregates, trickle the aggregates into the mold in such a way that it fills up just $1/3^{rd}$ the depth of the measuring cylinder. Then 25 smooth blows with the help of a tamping rod are given to create evenness and any air void. Now add more sample layers until the cylinder gets full. Then measure its weight. Turn over the sample into the huge cylinder. Bring the impact test machine to rest without wedging or packing up on the level plate, block or floor, so that it's rigid and the hammer guide columns are vertical. Lift the hammer to a height such that its face is 15’’ above the surface of the aggregate sample in the cup. Hold it tightly until it's completely ready to drop. The height of 380mm must be maintained for a while to grant proper grip. After lifting, let the hammer fall freely on the sample in the cylinder. A total of 15 blows are provided without any long interval between consecutive falls. Make sure to maintain the safety precautions while dropping the hammer as it may cause serious injury due to its heaviness. Do not leave the hammer, hold firmly the support with such a grip that 15 blows happen in one trial. The next step is to take out the cylinder from the machine, pour out the deteriorated impacted sample and sieve the sample by passing it through a 2.366m sieve. Weigh the mass passed through the sieve to calculate the mass loss from the actual sample. Calculate the aggregate impact value and repeat the steps for the other two samples to determine the best average in the end.

Specific gravity test

It’s tested to predict the rigidity of aggregates using Eq. (1). Standard code of test is ASTM C 127. The specific gravity of an aggregate is considered to be a measure of the strength or quality of the material. Aggregates that have a low value of SG are usually weaker than those with a higher SG value. It’s because a weaker value of specific gravity indicates a high percentage of air void present in the solid volume of aggregate. In this particular test the weight of the sample is recorded under three different sample conditions; dried sample (initial weight without any presence of moisture), Saturated Surface Dry (SSD, pores of aggregate are filled with water) and submerged in water (weight underwater). By using these three weights, the sample’s apparent SG, bulk SG, and bulk SSD SG can be found. A void analysis can also be done through this test. In this test going to use the default plastic composition. Because of all of this, the aggregate used in road pavement construction is bound to have a specific gravity between 2.4-2.7, where 2.7 is a typical value for limestone aggregate. Since not using limestone aggregate

Table 2: Specific gravity sample readings

Sample	Plastic Composition %	Bulk Specific Gravity g	Bulk SSD Specific Gravity g	Apparent Specific Gravity g	Average
1	12	2.539857832	2.555343996	2.57980918	2.569456
2	12	2.528690597	2.543351871	2.56631606	2.569456
3	12	2.527925196	2.541319181	2.562243852	2.569456

Table 3: Sample reading for moisture absorption

Sample	Plastic Composition %	Weight of Dry sample W3 g	Weight of Saturated Surface Dry W2 g	Weight in water W1 g
1	12	2000.9	2013.1	1225.3
2	12	2000.7	2012.3	1221.1
3	12	2000.6	2011.2	1219.8

to find value below it. Find the sample with maximum allowable apparent specific gravity and bulk specific gravity of polymer-coated aggregate [1, 30].

$$\text{Specific gravity}=\frac{\text{weight of dry aggregate}}{\text{weight of dry aggregate-weight of aggregate in water}} \tag{1}$$

First of all, collect aggregates and for the required size sieve them such that they retain in a 12.5 mm sieve and pass through 19.0 mm. After sieving, coat the separated aggregates with the standard 12% composition of PET bottles in a mixer. The mixture sample is taken out, washed, and dried in a way that no moisture remains in it and the balance displays constant reading for mass. This indicates that all the water has left the sample. After drying and weighing, submerge the PCA material sample in water taken in different pans and leave it soaking for 24 h. The submerged samples were soaked in water for 24 h taken out and set the mesh basket on the specific gravity weight balance. Transfer the sample in the basket from the pan and note down its weight underwater. Take the submerged weight and remove the mesh basket carefully from the bucket or container. Take out the sample from the mesh and spread the sample on a dry cloth. After some time, when the aggregates get dried properly that is no water remains. If required place them in the oven for 2 h. The readings for specific gravity tests are given in Table 2. The value W_3 is dry weight means the initial weight of the sample. W_2 is the saturated surface dry weight that is the weight after the sample was soaked for 24 hours and then dried. W_1 is submerged weight of water. Apparent and bulk specific gravity and Bulk SSD all are calculated using this W_1, W_2, and W_3 value. Among all these three values; bulk specific gravity is considered to be the lowest of the three, bulk SSD is intermediate, and apparent specific gravity is the highest.

Moisture absorption test

The moisture Absorption test is executed to determine how much water content is retained in the given sample after a certain amount of time. The difference in dry weight and weight after the test is calculated in terms of %. If the absorption is more, it indicates more porous material whereas a lesser absorption indicates high-quality aggregate having little porosity ratio. This can predict the performance of aggregates under humidity and different weather circumstances like heavy rains, and snowfall conditions [5, 8]. However, there is no specific value for this test but in reference, the moisture absorption for aggregates should be less than 3%. Standard code of test is ASTM C 127-88. Determine the moisture absorption of aggregates and predict the voids in the aggregates and study the effect of plastic composition on the pores of samples and validate the equipment with the best results. After the preparation of samples in the mixer that is equipment, separate the sample and oven dry it for 24 h and weigh the dry molded sample. After dry weighing the sample, place the sample in the container or bucket such that the water level is above the completely soaked material. Leave the sample soaked under water for 24 h. After a day brings the sample out of the container and dries the sample in a way that there's no water retained over the surface of the material. After adequate drying weighs the sample again and notes the readings given in Table 3.

Los Angeles abrasion test

The Los Angeles Abrasion test is vastly used as a measure of the relative quality of aggregates. It determines the deterioration of standard grading of aggregates when put under to abrasive load and impact in a circulating steel

Table 4: Grading table for sample

Grading	Number of Spheres	Weight of Aggregate (kg)
A	12	5
B	11	4.58
C	8	3.33
D	6	2.5

drum with an abrasive charge of balls made with steel. Standard code of test is ASTM C 131-89. Test the hardness and toughness of PCA material that helps to speculate the limit up to which the PCA can withstand abrasion offsets of traffic load for a long amount of time and obtain a high-quality material. Operating conditions for the Los Angeles abrasion test are; to set the rpm or revolution of the device to between 30-33 rpm [11, 14]. Use the steel ball bearings according to the weight of the sample as shown in Table 4. Aggregates must be of the required sieved size according to the demands of the sample. Aggregates should be clean from any dirt and impurities attached to the surface of it.

For each sample firstly we take 5 kg of aggregates and 2.5 kg of aggregates. The required sieved size should be between 19.0-25 mm for 5 kg and for 2.5 kg should be 12.0-9.5 mm. Wash the aggregates with water and pour this aggregate into the fabricated machine and coat the aggregates with 12% plastic content. After this, take out the prepared batch and separate 3 samples for testing. Note the weight of the sample before testing it. Place the samples of prepared polymer coated aggregate that is one sample at a time inside the drum of the equipment with sphere balls or charges according to the required grading. Set the rpm of the machine to 30-33 rpm and start testing the material for 500 revolutions. When the revolutions are completed take the sample out carefully in a large tray. Rotate and empty the drum in such a manner that the lid of the drum faces directly to the tray so that there is no loss of material. After taking out the sample tray, sieve the material through a 1.70 mm sieve and weigh the stayed material on the sieve. The mass that is lost is calculated in a % and considered as the abrasion value.

Stripping test

The concept of this test is to evaluate the resistance of bitumen to detach from the aggregate sample coated with plastic. Flexible and durable binding between the bitumen and aggregate conFigs. a longer life span of roads. But mostly the existence of water flowing on the road weakens the bond between bitumen and aggregate. Therefore, bitumen starts to get detached from the surface of the road. Involvement of plastic in the material shows improved and better binding strength and validates the objective of this test. The stripping value is expressed as a percentage of the amount of bitumen lost or stripped out from the aggregate. It is going to be filtered and weighed using an analytical machine balance [12, 20]. The test is performed to Fig. out the detached material content from the surface of the polymer-coated aggregate bituminous mix and predicts the standard plastic 12% composition gives the best quality result. Testing conditions for stripping test are; take 200 g of sample, the temperature of water bath set at 53 °C, and soaking time is 10 h.

Take 3 beakers of 500mL capacity, fill them with water and place 200 grams (0.2kg) sample in the beakers with 12% composition of the plastic. After placing the sample in a filled water beaker, leave them for 30-35 minutes to let the dust particles get removed from the sample. Set the Water Bath at 53 °C. Empty the water from the beakers and refill them with water and put them inside the water bath. Place the thermometer in the beaker of the sample to verify the accuracy of the water bath's set temperature. Leave the samples in the water bath for about 24 hours and make sure the water level is above the beaker's level. After 24 hours take out the samples from the water bath and let them cool for a bit. Then remove the samples from the filled beaker. Take the iron stand, fit the funnel with it and filter the water to find out the stripped bitumen from the PCA sample. Through visual inspection, the stripped bitumen is manifested on the filter paper. Filters paper is then dried and weighed in the end using an analytical balance.

RESULTS AND DISCUSSION

PCA is a replacement for asphalt-based road-making material. It is less permeable than conventional roads which result in minimal absorption of water. Hence, pothole formation becomes highly resistible. In PCA, a polymer layer is coated over aggregate and then bitumen is added at the end. Research has already been done by varying the composition of the plastic in the overall mixture and it is achieved that the 12% plastic composition material provides the most optimum results of different aggregate and bitumen tests within the range of 0-15%. The fabricated machinery is tested, where the tests are performed on three samples of 12% plastic composition and the fluctuation in the properties has been observed.

Table 5: Selection criteria for the best sample of Marshall stability

Parameters	Standard Value	Sample Preferred
Marshall Stability	680 kN (minimum)	Maximum value obtained with optimum air void%
Flow value	Heavy traffic 8-18	Least possible with the least voids
Air voids	Not more than 3%	Not less than 2%

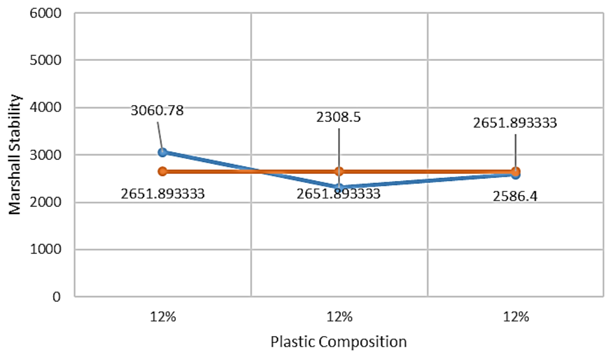

Fig. 5: Marshall Stability test of plastic composition

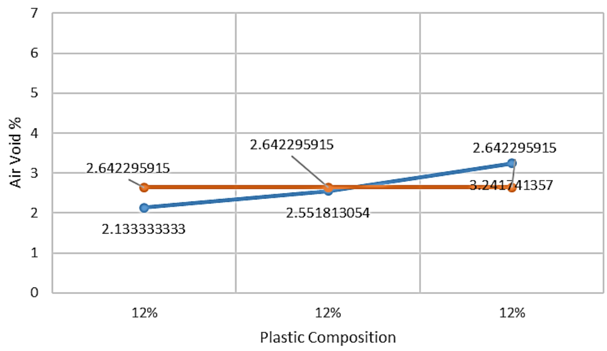

Fig. 7: Marshall stability test air void % of plastic composition

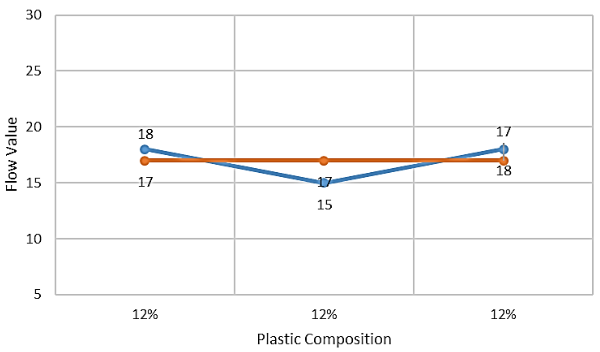

Fig. 6: Marshall Stability test flow value of plastic composition

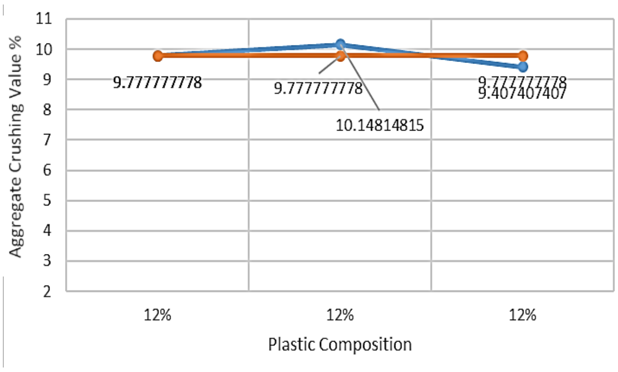

Fig. 8: Crushing test of plastic composition

Marshall stability

Marshall stability test is performed to determine the maximum load a test specimen can endure. An addition of plastic helps the bituminous PCA to resist the deformation due to the traffic load. Figs. 5, 6, and 7 are generated from the results of the Marshall stability value, flow value, and air void %. All these Figs. have minimal fluctuation in the mean value. The mean of Marshall stability value, flow value, and % air void are 2651.893kN, 17, and 2.642% respectively. All the values of each parameter satisfy the selection criteria that are mentioned in Table 5 [12, 20, 31].

Crushing test

The crushing test is used to find out the strength of coarse aggregates and its relative measure to the resistance of an aggregate to crushing undergoing slowly compression load applied. Aggregate crushing value is known as the percentage by weight of the material that is crushed when the test aggregates are put out under a specific standardized load condition. Fig. 8 is the graphical representation of the crushing value test. The mean ACV that is obtained is 9.778 [24, 27, 32].

Impact test

The resistance of instant impact, shock, or load can be determined through the impact value test. The firmness and strength of the aggregates can be examined through this test. Aggregates having lower impact value show high stability and toughness of aggregate and better economic performance [1, 29, 32]. The impact value test is graphically represented in Fig. 9. The mean AIV is observed as 7.627.

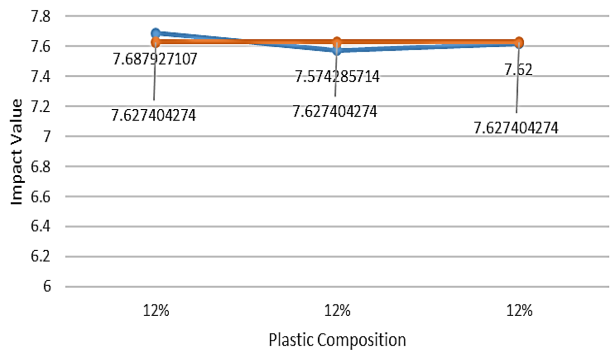

Fig. 9: Impact test of plastic composition

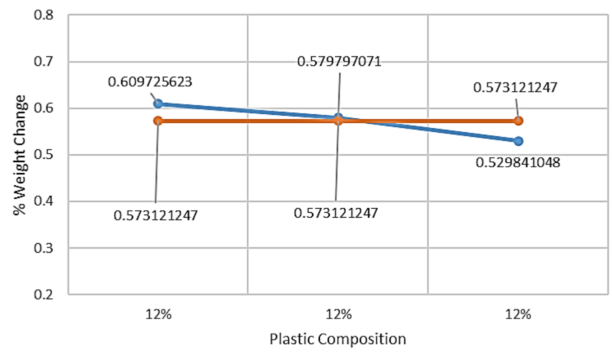

Fig. 11: Moisture absorption test of plastic composition

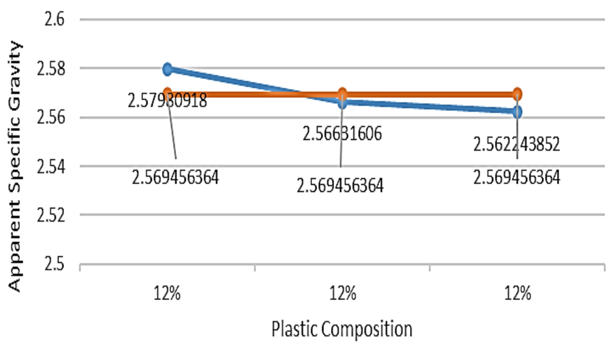

Fig. 10: Specific gravity test of plastic composition

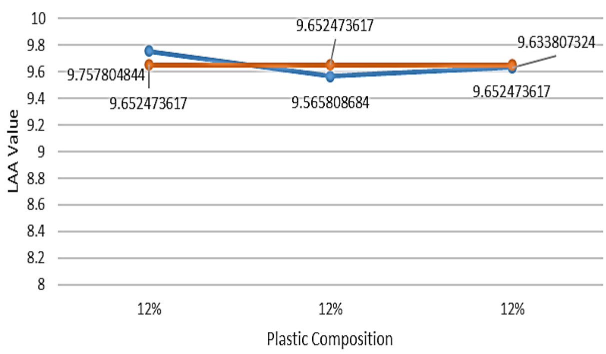

Fig. 12: Los Angeles abrasion test of plastic composition

Specific gravity test

The specific gravity of an aggregate is a measure of the strength or quality of the material. Aggregates that have a low value of SG are usually weaker than those with a higher SG value. It is because a weaker value of specific gravity indicates a high percentage of air void present in the solid volume of aggregate. Fig. 10 can observe that at constant 12% composition of plastic there is minimal fluctuation around the mean value. The mean value of specific gravity that is obtained is 2.569, which is greater than the conventional aggregate specific gravity value of 2.39 [13, 22, 26].

Moisture absorption test

A moisture absorption test is performed to determine how much water content is retained in the given sample after a certain amount of time. The difference in dry weight and weight after the test is calculated in terms of %. If the absorption is more, it indicates more porous material whereas a lesser absorption indicates high-quality aggregate having little porosity ratio. It can predict the performance of aggregates under humidity and different weather circumstances like heavy rains, and snowfall conditions. The moisture absorption test results are graphically observed in Fig. 11. The mean value that obtained is 0.573. It shows that the produced PCA material has low water absorption capability [10, 15, 22].

Los Angeles abrasion test

Los Angeles abrasion test determines the deterioration of standard grading of aggregates when put under to abrasive load and impact in a circulating steel drum with an abrasive charge of balls made with steel. In Fig. 12 there are the results of the Los Angeles abrasion test. 9.652 is the mean abrasion value observed [2, 8, 22].

Stripping test

A stripping test is done to know how well bitumen and tar stick to the surface of aggregates. The problem of stripping arose when the bituminous mixture is in contact with water as bitumen is permeable to water. The concept of this test is to evaluate the resistance of bitumen to detach from the aggregate sample coated with plastic. Flexible and durable binding between the bitumen and aggregate

Table 6: Stripping test readings

Sample	Plastic Composition %	Weight mg	Weight Detached mg	Ratio mg	% Loss
1	12	200000	392.68	0.0019634	0.19634
2	12	200000	448.25	0.00224125	0.224125
3	12	200000	342.75	0.00171375	0.171375

Table 7: Test result comparison

Tests	Lab-Scale Test Results	Pilot Plant Test Results	% Error
Marshall Stability Test	3607.335	2651.893	26.486
Crushing Test	12.528	9.778	21.951
Impact Test	6.542	7.627	16.585
Specific Gravity Test	2.608	2.569	1.495
Moisture Absorption Test	0.34	0.573	68.529
Los Angeles Abrasion Test	7.78	9.652	24.062
Stripping Test	0.485	0.197	59.381

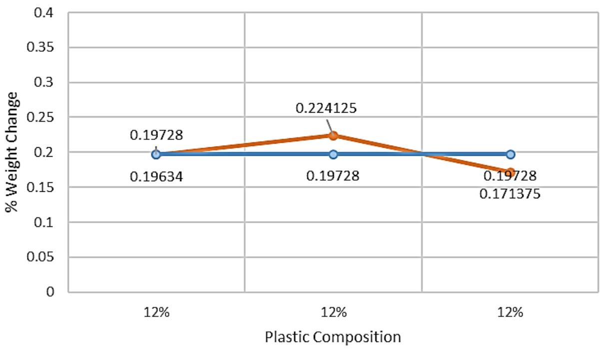

Fig. 13: Stripping test of plastic composition

conFigs. a longer life span of roads. The readings and calculations of the stripping value test are shown in Table 6. In Fig. 13 the results are graphically represented. The mean value of the stripping test that is obtained is 0.197%, which shows that there is almost negligible stripping of bitumen from the surface of PCA [4, 23, 32].

In Table 7, a comparison can be observed between the mean values of tests performed on the samples that are produced using the pilot plant and the values of the same tests which have been performed on the samples that are produced in the lab. The error between the two values is due to the difference in consistency of the mixture of the lab-scale and pilot plant scale. In the stripping test, a significant error is observed because the pilot plant sample provided improved results [33]. Hence, after observing the minimum deviation from the mean value in each of the tests at constant 12% plastic composition and by comparing the mean values with the lab-scale test results the fabricated pilot plant has been validated and it can be concluded that the PCA material produced from this pilot plant is fit for the commercial use [11, 14, 20].

CONCLUSIONS

This particular experimental project was initiated with the designing of a type of equipment that ought to give us the best product of polymer-coated aggregate material. However, the comparison between polymer-coated aggregate roads and regular commercial roads has already been a topic of discussion and throughout these arguments, PCA was proven to be a better paving material than other commercial-based roads. To explore the predictive relationship between the plastic composition and enhancement in properties of the road material. With different tests, they concluded that 12% plastic content is the optimum composition for PCA-based roads. Then picking up the 12% plastic composition as the standard raw material to be used in the production of plastic-coated aggregate and eventually we concluded our design of a mixer and whole machine. After the designing section of a machine, started working on its fabrication. The assembled machine consists of only one major unit. After the manufacturing of the equipment, collected the required raw material which is aggregates of different sieved sizes, waste PET bottles, and bitumen. After that, the sample product from the machine was poured out and the testing part; the seven tests of aggregate began with each batch sample from the machine to validate the working and product quality of the fabricated mixer. Fortunately, the obtained results from the samples came out to be within the limited and optimum values. The comprehensive costing and economic analysis demonstrate that the scope of the commercial scale pilot plant of PCA-based road making is satisfactory and seemly for the small commercial scale, the repairing of potholes, small parking lots, and small streets. It can be concluded that the fabricated rotary mixer gives us an adequate PCA product with suitable enhancement of binding properties for pavement of roads. In the future, this method of producing road materials should be implemented commercially to manage the waste plastic as well as improve the quality and life of roads. As established the idea of producing roads from PCA material through multiple tests that it minimizes the deterioration of roads and helps them prolong their life. Thus recommend that; after the production pilot plant, a full commercial scale machine should be produced to produce the PCA material. Advanced research should be done to verify the existing method of production of PCA material and adjustments should be made in the pilot plant according to the latest research. A few meters of the commercial road should be laid using the pilot patch to check the real-time performance of PCA material.

Acknowledgments

The authors would like to acknowledge the Department of Chemical Engineering and Department of Polymer and Petrochemical Engineering, NED University of Engineering & Technology, Karachi, Pakistan, for supporting this research work.

Abbreviation

°C	Degree Celsius
PE	Poly ethylene
PCA	Polymer coated aggregates
TG	Temperature gauge
LAA	Los Angeles abrasion
ACV	Aggregate crushing value
AIV	aggregate impact value
ASTM	American society for testing material
AASHTO	American association of state highway and transportation officials
SSD	Saturated surface dry

Received : Dec.14, 2022 ; Accepted : May.22, 2023

REFERENCES

[1] Wang B., Yan L., Fu Q., B Kasal., A Comprehensive Review on Recycled Aggregate and Recycled Aggregate Concrete, *Resour., Conserv. Recycl.*, **171**: 1-29 (2021).

[2] Reis G.S.D., Quattrone M., Ambros W.M., Grigore Cazacliu B., Hoffmann Sampaio C., Current Applications of Recycled Aggregates from Construction and Demolition: A Review, *Materials*, **14**: 1-21 (2021).

[3] Kim J., Construction and Demolition Waste Management in Korea: Recycled Aggregate and Its Application, *Clean Technol. Environ. Policy*, **23**: 2223-2234 (2021).

[4] Loureiro C.D.A., Moura C.F.N., Rodrigues M., Martinho F.C.G., Silva H.M.R.D., Oliveira J.R.M., Steel Slag and Recycled Concrete Aggregates: Replacing Quarries to Supply Sustainable Materials for the Asphalt Paving Industry, *Sustainability*, **14**: 1-31 (2022).

[5] Barbieri V., Lassinantti Gualtieri M., Manfredini T., Siligardi C., Lightweight Concretes Based on Wheat Husk and Hemp Hurd as Bio-Aggregates and Modified Magnesium Oxysulfate Binder: Microstructure and Technological Performances, *Constr. Build. Mater.*, **284**: 1-13 (2021).

[6] Biswas A., Goel A., Potni S., Performance Evaluation of Sustainable bituminous- Plastic Roads for Indian Conditions, *Int. J. Eng. Adv. Tech.*, **9**: 6384-6392 (2019).

[7] Asare P.N.A., Kuranchie F.A., Ofosu E.A., Verones F., Evaluation of incorporating plastic wastes into asphalt materials for road construction in Ghana", *Cogent Environ. Sci.*, **5**: 1-13 (2019).

[8] Lopresti M., Palin L., Alberto G., Cantamessa S., Milanesio M., Epoxy Resins Composites for X-ray Shielding Materials Additivated by Coated Barium Sulfate with Improved Dispersibility, *Mater. Today Commun.*, **26**: 1-12 (2021).

[9] He Y., Chen Q., Zhang Y., Y Zhao., Chen L., H_2O_2-Triggered Rapid Deposition of Poly(caffeic acid) Coatings: A Mechanism-Based Entry to Versatile and High-Efficient Molecular Separation, *ACS Appl. Mater. Interfaces*, **12**: 52104-52115 (2020).

[10] S Jawalkar.G., Plastic Waste Shredded Bitumen Road, *Int. J. Adv. Scient. Res. Eng. Trend.*, **4**: 16-20 (2019).

[11] Alave. B.Y., Mahimkar S.S., Patil K.S., Gupta J.J., Kazi A., Experimental Investigation of Plastic Coated Aggregate, *Int. J. Eng. Res. Tech.*, **9**: 112-120 (2021).

[12] Abhishek K., Kumar V.R., Datta S., Mahapatra S.S., An Integrated Multi-Response Optimisation Routecombining Principal Component Analysis, Fuzzy Inference System, Nonlinear Regression and JAYA Algorithm: A Case Experimental Study on Machining of GFRP (epoxy) Composites, *Int. J. Ind. Sys. Eng.*, **32**: 497-525 (2019).

[13] Crusho A.B, Verghese V., Medical Plastic Waste Disposal by Using in Bituminous Road Construction, *Int. Res. J. Multi. Techno.*, **1**: 668-676 (2019).

[14] Kočí V., Petříková M., Fořt J., Fiala L., Černý R., Preparation of Self-Heating Alkali-Activated Materials Using industrial Waste Products, *J. Cleaner Prod.*, **260**:1-8 (2020).

[15] Rezaei M.R., Abdi Kordani A., Zarei M., Experimental Investigation of the Effect of Micro Silica on Roller Compacted Concrete Pavement Made of Recycled Asphalt Pavement Materials, *Int. J. Pavement Eng.*, **21**: 1-15 (2020).

[16] Khan R.M., Mushtaq A., Material Selection and Manufacturing of Halogen-Based Headlamp for Two-Wheeler Vehicle Technologies, *Iran. J. Chem. Chem. Eng. (IJCCE)*, **41(1)**: 88-108 (2022).

[17] Kolge N., Konnur B.A., Special Issues on Bitumen and Bitumen Modification for Use in Hot Mix Asphalt (HMA): Review, *Int. Res. J. Eng. Tech.*, **6**: 4012-4015 (2019).

[18] Lu Z., Kong X., Zhang C., Cai Y., Effect of Highly Carboxylated Colloidal Polymers on Cement Hydration and Interactions with Calcium Ions, *Cem. Concr. Res.*, **113**: 140-153 (2018).

[19] McBride M., Persson N., Reichmanis E., Grover M., Solving Materials' Small Data Problem with Dynamic Experimental Databases, *Processes*, **6**: 1-17 (2018).

[20] Neelapala Naresh D., Suryaprakash P.V., Polymer Modified Bitumen in Flexible Pavement and Its Characterization, *Int. J. Analyt. Exp. Modal Analy.*, **12**: 65-71 (2020).

[21] Tariq S.M., Mushtaq A., Ullah A., Qamar R.A., Ali Z.U., Afshan S., Preparation of Polymer-Coated Aggregate by Utilization of Waste Plastic for Pavement of Roads, *Bulg. Chem. Commun.*, **53**: 294-306 (2021).

[22] D. Movilla-Quesada, A.C. Raposeiras, J. Olavarría, Effects of Recycled Polyethylene Terephthalate (PET) on Stiffness of Hot Asphalt Mixtures, *Adv. Civ. Eng.*, **2019**: 1-6 (2019).

[23] Hariharasudhan C., Breetha Y.J., Kumar E.P., Abirami S., Experimental Study on Use of Plastic Electronics Wastes in Pavement Blocks, *J. Comput. Theor. Nanosci.*, **17**: 3680-3683 (2020).

[24] J Dulinska-Litewka., Lazarczyk A., Halubiec P., Szafranski O., Karnas K., Karewicz A., Superparamagnetic Iron Oxide Nanoparticles-Current and Prospective Medical Applications, *Materials*, **12**: 1-26 (2019).

[25] J Kumar., Kumar Verma R., A novel Methodology of Combined Compromise Solution and Principal Component Analysis (CoCoSo-PCA) for Machinability Investigation of Graphene Nanocomposites, *CIRP J. Manuf. Sci. Tech.*, **33**: 143-157 (2021).

[26] Tran N.P., Gunasekara C., Law D.W., Houshyar S., Setunge S.., Cwirzen A., A Critical Review on Drying Shrinkage Mitigation Strategies in Cement-Based Materials, *J. Build. Eng.*, **38**: 1-17 (2021).

[27] C S T.S., V K., Fayaz S., Goudathi A.C., Experimental Investigation on Partially Replacement of Bitumen with Waste Materials for Flexible Pavement Construction, *Int. J. Current Eng. Scient. Res.*, **6**: 10-18 (2019).

[28] Kusoglu I.M., Donate-Buendia C., Barcikowski S., Gokce B., Laser Powder Bed Fusion of Polymers: Quantitative Research Direction Indices, *Materials*, **14**: 1-25 (2021).

[29] Margaritis A., Soenen H., Fransen E., Pipintakos G., Jacobs G., Blom J., Van den Bergh W., Identification of Ageing State Clusters of Reclaimed Asphalt Binders Using Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) Based on Chemo-Rheological Parameters, *Constr. Build. Mater.*, **244**:1-13 (2020).

[30] Madiona R.M.T., Winkler D.A., Muir B.W., Pigram P.J., Effect of Mass Segment Size on Polymer ToF-SIMS Multivariate Analysis Using a Universal Data Matrix, *Appl. Surf. Sci.*, **478**: 465-477 (2019).

[31] Lu G., P Liu., Y Wang., Faßbender S., Wang D., Oeser M., Development of a Sustainable Pervious Pavement Material Using Recycled Ceramic Aggregate and Bio-Based Polyurethane Binder, *J. Cleaner Prod.*, **220**: 1052-1060 (2019).

[32] Colangelo F., Messina F., Di Palma L., Cioffi R., Recycling of Non-Metallic Automotive Shredder Residues and Coal Fly-Ash in Cold-Bonded Aggregates for Sustainable Concrete, *Compos. B. Eng*, **116**: 46-52 (2017).

[33] Gurpreet S., Chauhan R., A Study on Using Plastic Coated Aggregate for Evaluation of Modified Bituminous Concrete Mix *IOP Conf. Ser.: Mater. Sci. Eng.*, **955**: 1-9 (2020).