Effects of Eggshell as a filler material on various bituminous mix: A review

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Summary / Abstract:

As the world gets innovative, people are finding different applications of waste by-products instead of using the age-old tradition of burning and land-filling techniques. These techniques also help in achieving better air & water quality and as a whole in achieving a greener environment. Using waste materials to construct pavement have been one of the new ways to reduce construction cost and one of which is using of eggshell as modifier. Applying modifiers in the asphalt mix improves the overall pavement performance and this is one way of partially replacing the Portland cement in the mix. The study evaluated the sustainable performance obtained by adding eggshells in varying rate, keeping in mind the optimum bitumen content (OBC) along with optimum eggshell content (OESC) and the OESC turned out to be at the range of 3% to 5% in most of the studies showing favourable conditions in terms of stability, flow, VFB, VTM, density etc. However, many research works have been undertaken in this field but with less practical application.

Keywords: Asphalt, Eggshell, Filler, OBC, OESC.

1. Introduction:

Pavement can be mainly divided into flexible pavement and rigid pavement where the transfer of load differs from one another. In terms of flexible pavement, the deformation of subgrade plays an important role with load transferring from one grain to another grain. The characteristic of load distribution depends on the design criteria. Slab action plays a big role in case of rigid pavements which are either made by cement concrete or prestressed concrete. However, during the construction phase of these pavements the production of waste materials can be huge and thereby it is difficult to get rid of the un-wanted materials. This may result in environmental damage causing degradation of air, water and even the appearance. Here, the best option is to recycle the by-products and make maximum use of it.

Now-a-days waste products are used as a filler or modifier in pavement construction with the objective to increase the physical or chemical properties and also to decrease the cost of construction. For the past few years many researches have been undergone to improve the road construction methods by using alternative processes. One of the most important filler materials used is Portland cement but the demand for cement has been increasing and to solve this problem, using of filler materials are highly encouraged. One of the easily available filler materials is the eggshell.

According to various studies conducted, using eggshell powder as modifier can enhance the sustainable performance, which is achieved by obtaining the optimum bitumen content as well as the optimal eggshell content (OESC). This paper will show how effective the eggshell can be as a filler in bitumen mix for the construction of asphalt pavement, considering the availability, fire and climate change resistivity, chemical components and physical properties.

2. Objectives:

1) To enhance the property of aggregates and bitumen.
2) To determine the percentage addition of egg shell powder (ESP).
3) To check the thickness criteria for pavements.
4) To promote the use of recycle fillers and support application of green products.
5) Lastly to be cost effective material.

3. Materials Used:

1) **Aggregates:** Both fine and coarse aggregates were used which were further crushed to provide that interlocking bond in between and act against the friction. Aggregates are also termed as granular materials which has a mixed composition of gravel, sand, stones, etc. Fine aggregates of angular shape are best preferred and using the natural sand in the construction phase serves the best result. The basic characteristic of aggregate is that it serves as a reinforcement which helps in achieving the overall physical strength with various applications such as road side drainage, foundations, base material for pavements, etc.
2) **Bitumen:** The naturally available mixture obtained through the process of distillation. The main purpose is to use the bitumen as binder material with good quality such as waterproof and adhesion. As the bitumen has its viscos-elastic property it is likely to achieve permanent deformation and cracks. Moreover, the chemical composition of bitumen varies depending as per the source of crude oil. Around 85% of roads around the world are constructed using bitumen which offers an economical and more sustainable option.
3) **Eggshell:** Eggshell shall be used as filter material and mostly in powdered form to fill up the cavities in the bituminous mix for pavement construction. Further the filler can increase the stability and with almost about 47% of skeletal calcium it has high resistance to fire and climate change. With high CaO content and other elements such as Al_2O_3, SiO_2, Cl, MnO, etc it has a brittle nature, which can form a powdery substance easily. Most of the eggshells used in the study were obtained by collecting from air-dried and crushed into smaller particles.

4. Literature Review:

KA Marsi et al. (2021) The application of Stone Mastic Asphalt (SMA) is to improve the durability of pavement and is widely used in many countries around the world due to their ability to withstand deformation. However, the chances of getting cracks, ruts can be seen over time as the pavement ages or due to temperature effects. So, varying percentage of eggshells were added to stone mastic asphalt mixture along with the laboratory tests such as Abrasion test and Marshall stability test. And addition of eggshell powder in the mixture results in higher stability thereby enhancing the Stone Mastic Asphalt mixture.

Aws M. Nejres et al. (2020) The enhancement of physical and rheological properties of Natural Asphalt (NA) can be achieved by adding alternative materials and natural asphalt being a viscous material it has long hydrocarbon chains. The presence of resins can determine the quality and properties of Natural Asphalt. As per the study obtained by Al-qayyarah (Iraq), alternate materials and food waste such as eggshell powder were added to the natural asphalt in different ratios. As a result of which the rheological properties were improved and considering the conditions at Iraq the favourable ratio of ESP was 15%. Again, checking the physiological study, the eggshells were scattered uniformly and this was one of the reasons leading to formation of an improved asphalt mix that can withstand external forces as well as weather conditions.

Bethelehem Yenesew et al. (2020) Carried out various tests on the virgin asphalt as well as on modified asphalt in which ESP were added by weight of asphalt. As part of the investigation ESP percentage were considered as 3%, 6%, 9% by weight of asphalt. The important aspect was to check the rheological property on both the RTFO aged and unaged binders which was proved that addition of ESP can decrease the penetration value along with reduction of ductility value but increase in softening point value. So, the research concluded with 6% ESP as the optimum percentage for modification process.

Arman Hamidi et al. (2019) They did a research to check the effects of filler and the ability to withstand the rutting. The normally used fillers were silica sandstone powder and Portland cement while the researchers examined the content of recycled eggshell powder along with laboratory investigation three different filler contents plus the optimum binder content were determined. The comparison between the permanent strain after 10 minutes of recovery (PS-660) and the permanent strain after 60 seconds of recovery (PS-120) were used to check the potential of rutting. The study considered some important factors namely primary and secondary slope phases, binder percentage creep curve, which demonstrated that the application of fillers can clearly influence the rutting resistance.

Ghadash Ghassan Masued (2019) Eggs are used in every household, restaurants and even from chicken farms that generates huge quantities of eggshells as domestic waste and its application as filler can be an inexpensive option as compared to other filler type. Moreover, research was conducted to compare the performance by differing the eggshell powder percentages (0,3,6,9,12,15,20,25,100%).

T. Zaman et al. (2018) The potential of eggshell as a raw material in the field of soil stabilization, filler for bitumen mix or as biomaterial formation were studied by the team. Both calcined and uncalcined eggshells were taken as part of the study and turned out that calcined eggshells are good mixture of lime and portlandite

phase. Considering the qualitative study it was shown that CaCO3 as the major component with more than 90% of it possessing rhombohedral structure. And during the semi-quantitative analysis the appropriate temperature for calcination was considered as 800 degree Celsius as the synthesis of Ca0 is preferable in this case.

N Parthasarathi et al. (2017) In order to minimize the use of cement and reduce the construction cost, the best replaceable materials are considered to be ESP and silica fume. So, the investigation was done by adding ESP in the proportion of 5%,10%, 15% while considering the silica fume as 2.5%, 5%, 7.5% with respect to weight of cement. Further, extensive experiment was carried out to compare the strength by adding silica fumes and in another case by adding only ESP which proved that ESp alone can provide high strength even without adding silica fume. 15% was the appropriate percentage of ESP to get the desired flexural strength.

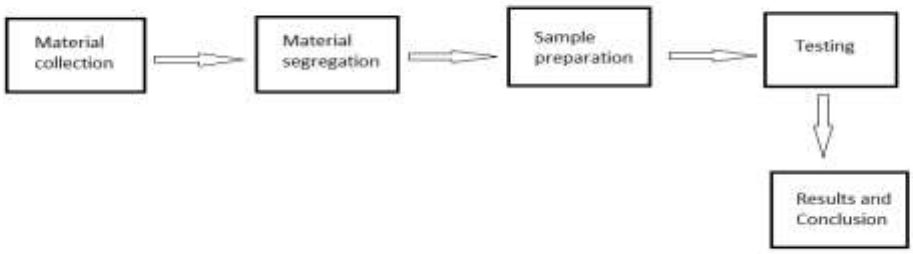
Yuliarahmadila et al. (2015) As per the study done in 2015, it showed that eggshell as a filler can partially replace the Portland cement in asphalt mixture. Performance of different eggshell content was observed by differentiating the eggshell powder amount. As a result of the research work it showed that the effective amount of eggshell content ranges from 3% to 5%.

Muthu Kumar M et al. (2014) As the study was based in Tamil Nadu and being the second largest egg consumer in India, a huge amount of eggshell waste had been generated per year. It showed how ESP was used to improve the soil stability where proportions of ESP were considered in between 0.5% to 5.5% with each interval of 0.5%. however, the appropriate or optimum ESP was 3% with increase in unconfined compressive strength.

D. Gowsika et al. (2014) As eggshells contain growing layers of CaCO3 with three innermost layers comprising the outermost membrane of egg. With high content of Magnesium Carbonate (lime), eggshells are sun-dried and used as modifiers or as a partial replacement in cement mortar mix. Other admixtures were also involved such as saw dust ash, fly ash, silica along with 5% of ESP. it was observed that addition of ESP beyond 5% can affect the compressive strength while split tensile strength increased with the addition of micro-silica.

5. Methodology:

Material collection takes place from different locations such as homes, restaurants and even from chicken hatcheries where eggshells are generated as domestic waste. Eggshell being inexpensive, it is available easily and readily. This is followed by material testing and segregation depending on the different weight categories and sizes, grouping it as pullet, small, medium, large and extra-large. For sample preparation, it generally depends on the Marshall Design method to set the optimum bitumen content along with the proper mixing and compaction process.



Eggshells have different layers with high resistance to fire and climate change. The outer layer of eggshell comprises 47% of Calcium content. For the process of implementing eggshell to asphalt first it is dried properly and broken down into smaller pieces until it forms a powdery substance. Then the powdered eggshells are stored under favourable room temperature. Moreover, sieve analysis takes place to determine the different sizes of aggregates.

It is necessary to check the specific gravity of each and every substance used followed by determining the void with bitumen. Above that it is important to acquire the optimum bitumen content and a comparison is made with the optimum eggshell content.

5.1 Sample preparation/ Testing:

Marshall design is used to check the quality, stability, adequate voids content and the durability along with determining the aggregate mix and the optimum bitumen content. It is also defined as the process to select the aggregate grades, specific gravity, the favourable compaction temperature and ability to flow.

5.1.1 Aggregate grading:

According to the UTHM laboratory (University Tun Hussein Onn Malaysia), the aggregate specification was based on the AC14 design. The table below shows the grading of aggregate as per the sieve analysis.

Sieve size(mm)	%Sieve passing	Average (%)	Retained (%)
20	100	100	-
14	90-100	95	5
10	76-86	81	14
5	50-62	56	25
3.35	40-54	47	9

1.18	18-34	26	21
0.425	12-24	18	8
0.15	6-14	10	8
0.075	4-8	6	4
Pan	-	-	6

Table 1: Aggregate grading as per Marshall test

5.1.2 Specific gravity and Bulk specific gravity:

Material	Specific Gravity	Specific Gravity (Aggregate mix)	
		Modified filler (%)	Total SG
Bitumen	1.01	0%	2.612
Coarse Aggregate	2.555	1%	2.600
Fine Aggregate	2.613	3%	2.586
Filler (Cement Portland)	3.120	5%	2.573
Filler (Eggshell)	2.363	3.375%	2.584

Table 2: Specific gravity of sample materials & aggregate mix

Right before the Marshall test specific gravity of all the materials are determined and are given below for both the sample materials and for the mix aggregate. While table:3 shows the bulk specific gravity as per the Jakarta conditions after compacting and cooling down the sample at room temperature.

Conventional Sample		Modified bitumen with OBC	
Bitumen Content (%)	Bulk Specific Gravity	Egg Shell Content (%)	Bulk Specific Gravity
4.5	2.269	0	2.302
5.0	2.306	1	2.292
5.5	2.314	3	2.302
6.0	2.348	5	2.294
6.5	2.323	-	-

Table 3: Bulk specific gravity of conventional sample & modified sample

5.1.3 Optimum Bitumen Content (OBC):

Optimum Bitumen Content (OBC) was checked as per the Marshall Test in order to produce the asphalt concrete with modifiers. Different graphs were plotted such as for stability, void in total mix (VTM), void filled with Bitumen (VFB), flow, stiffness, etc. The OBC obtained was based on the bitumen content on 4.5% to 6.5% and as result of the graphs observed 3.58% was accepted as the value of Optimum Bitumen Content.

Parameter	Wearing Coat	Result
Stability, S	500 kg	980 kg
Flow, F	2.0 mm	3.15 mm
Stiffness, S/F	250 kg/mm	296 kg/mm
Void in Total Mix, VTM	3.0 – 5.0 %	3.40 %
Void Fill with Bitumen, VFB	75 – 85 %	79%

Table 4: Parameters for OBC value

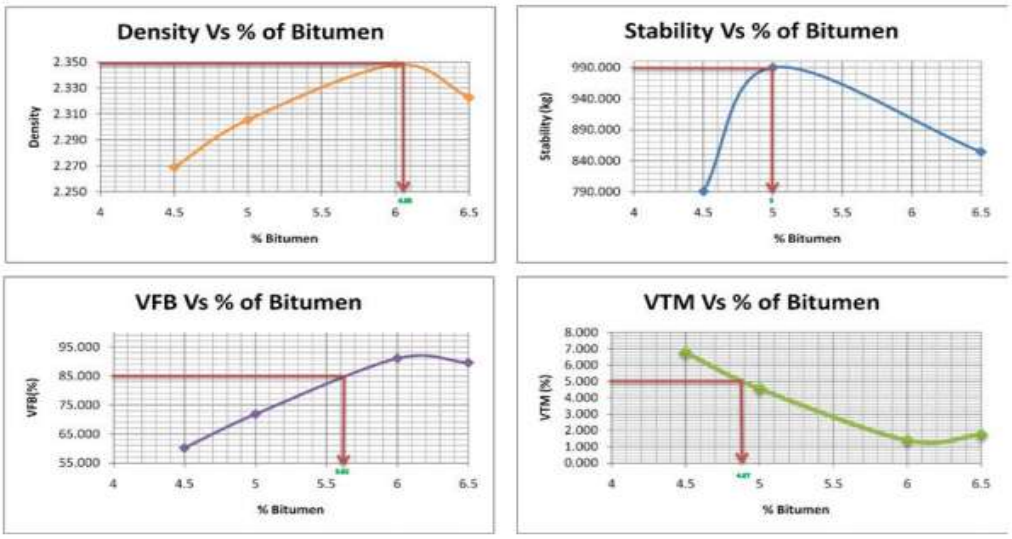


Figure 1: Graphs representing the parameters to calculate OBC

5.1.4 Optimum Eggshell Content:

As the Optimum Bitumen Content had been obtained, eggshells are added as modifier with further Marshall analysis to compare the asphalt concrete with and without eggshell. The figure below indicates the parameters checked to obtain the optimum eggshell content.

Marshall Parameter	Eggshell Content			
	0%	1%	3%	5%
Stability (kg)	921.094	1013.40	1115.16	1072.55
Flow (mm)	2.500	3.76	3.74	2.82
Stiffness (kg/mm)	370.28	271.35	301.85	613.66
VTM (%)	4.330	4.400	3.511	3.406
VFB (%)	74.029	73.517	77.839	79.374
Specific Gravity	2.612	2.600	2.573	2.573

Table 5: Parameters based on eggshell content

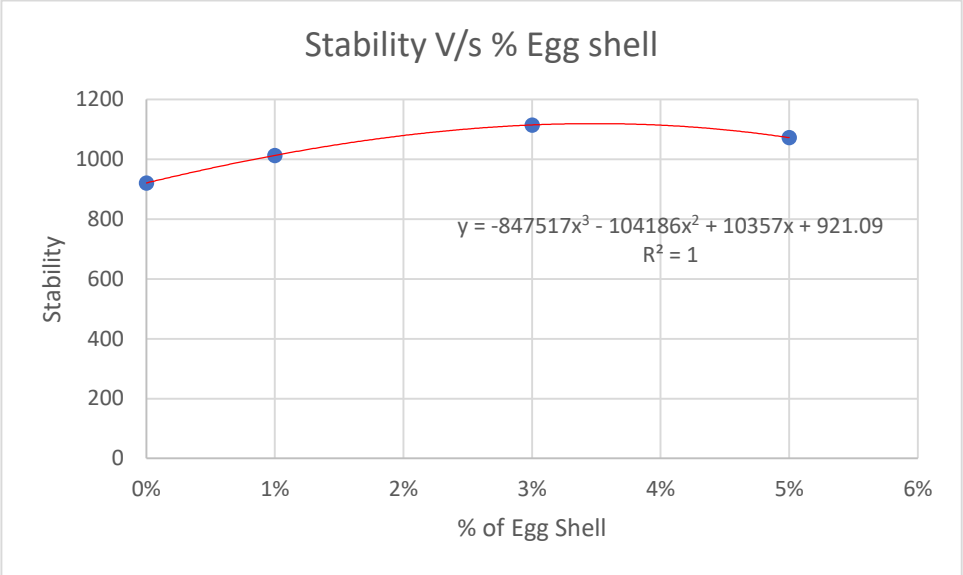
6. Review Result:

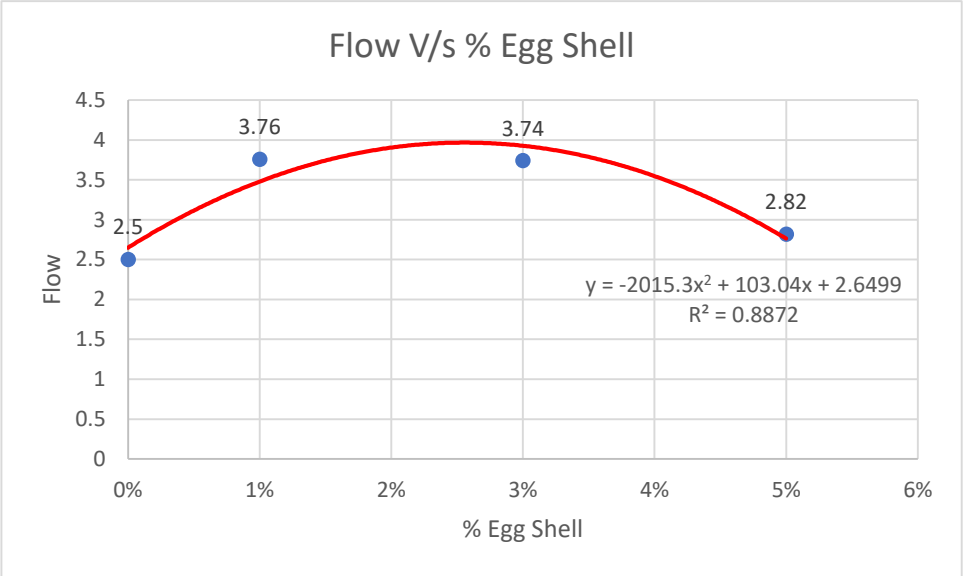
Comparing the results obtained from Marshall Test between the conventional sample and the modified sample, the data obtained were almost the same however, in terms of stability the modified sample turned out to be better proving that optimum eggshell content needs to be considered with respect to optimum bitumen content.

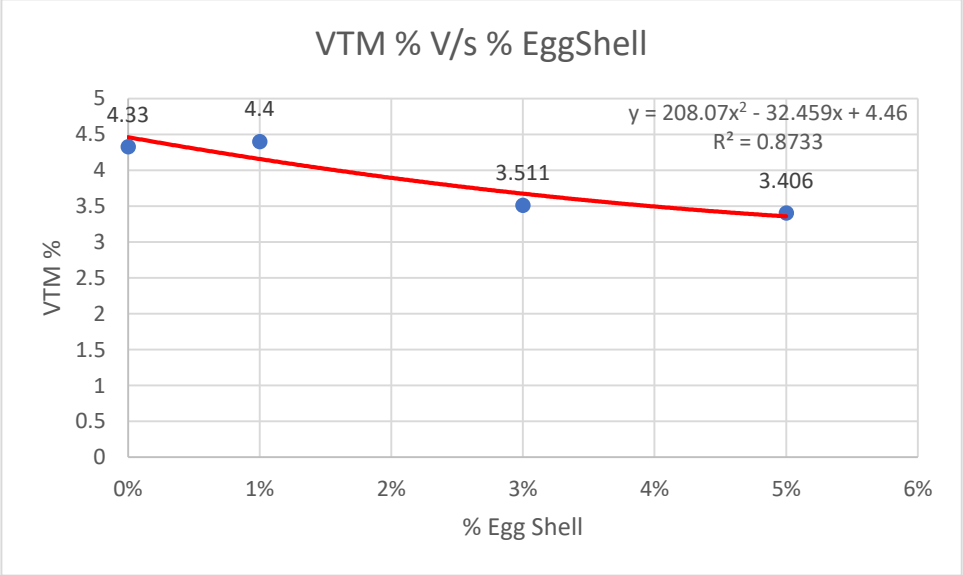
The study further showed that considering the JKR (Jakarta) specifications and varying the eggshell content (0%,1%,3%,5%), the stability of the mixture proved the ability to resist traffic deformation due to continuous loading. As the eggshell content increases stability increases but to the point till it reaches 5%, there will be decrease in strength. Moreover, the eggshells can fill the cavity in between the aggregates making sure that the flow remains proportional to the flexibility and as per the graph it had been observed that the flow value was not constant.

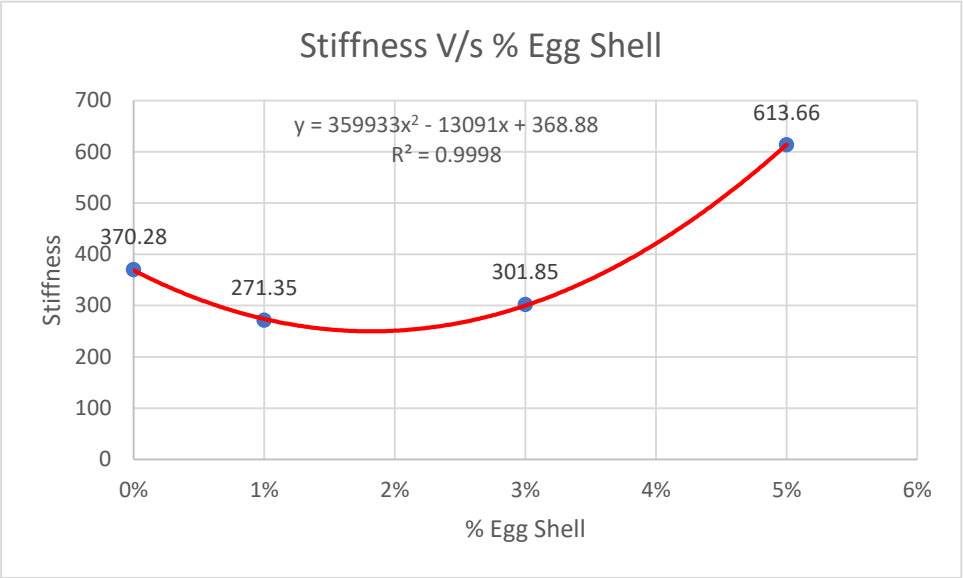
In terms of VFB with the increase in eggshell content the amount of bitumen absorption did not remain uniform throughout. Further, from the graph when eggshell content was 1%, the flow rate increases and decreases gradually at 5%. But, opposite goes for stiffness where the values reached its peak when eggshell content was 5%.

So, it had been observed that the values for flow and stability increases at 1% of eggshell content, while opposite characteristics were witnessed at 3% of eggshell showing how the values were not in uniform order. As an overall, the study showed the favourable eggshell content to be around 3% to 5%.


Stability V/s % Egg shell
Stability
% of Egg Shell
y = -847517x³ - 104186x² + 10357x + 921.09
R² = 1
1200
1000
800
600
400
200
0
0%
1%
2%
3%
4%
5%
6%


Flow V/s % Egg Shell
Flow
% Egg Shell
3.76
3.74
2.82
2.5
y = -2015.3x² + 103.04x + 2.6499
R² = 0.8872
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0%
1%
2%
3%
4%
5%
6%


VTM % V/s % EggShell
VTM %
% Egg Shell
4.33
4.4
3.511
3.406
y = 208.07x² - 32.459x + 4.46
R² = 0.8733
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0%
1%
2%
3%
4%
5%
6%



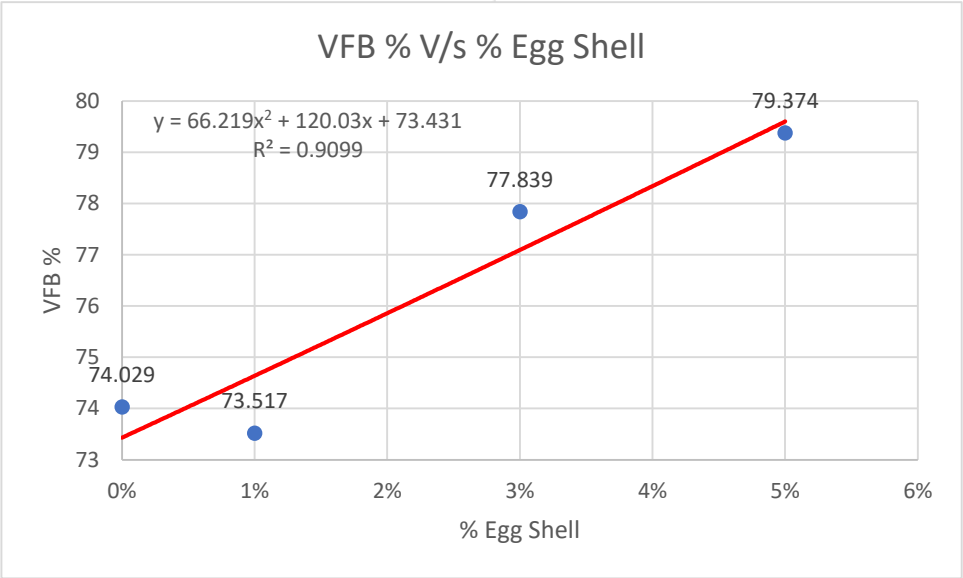


Figure 2: Graphs representing the parameters based on addition of eggshell

7. Conclusion:

Considering the different reviews, involvement of various eggshell content can be clearly visible proving that the use of eggshell as a filler material can produce overall good results. And since it is an easily available waste by-product the application can be a favourable approach. To sum it up from different researches done by different scholars, eggshell can be partial replacement of concrete. Last but not least the construction cost reduces leading to more innovative green pavements. Most of the studies proved the favourable ESP content to lie between 3.5%-5% depending on the surrounding conditions and tests associated.

The application of such pavements can bring great change in a country like India considering the fact that most of the eggshell wastes are dumbed at landfills or burned. Though there is a need of more tests and research works in this field in order to enhance the application of eggshells as filler material. The above data

can be used as a reference for further studies and this will help in coming up with more sustainable method to apply eggshell. Therefore, a lot of work can be done plus it will give another reason to construct infrastructures which are economical as well as eco-friendly.

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