DESIGN AND FABRICATION OF FIBERGLASS BASED ASPHALT ROOF SHINGLES FOR CONSTRUCTION INDUSTRY

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Certificate

This is to certify that work in this thesis has been carried out by **Mahurkh Mahmood** and **Mariam Tabarik,** and completed under my supervision in polymer laboratory, school of chemical and materials engineering, National University of Sciences and Technology, H-12, Islamabad, Pakistan.

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To our families,

And all of our friends

Without whom none of our success would be possible

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"All praise belongs to Allah, Lord of all worlds. Who created Heaven and earth and all that is between the two and indeed in them here are signs for those who seek."

We are forever grateful to Allah (SWT) for His countless blessings upon us. It is through His guidance that we stand where we are in our lives.

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ABSTRACT

Asphlat roof shingle is a roof covering, widely used for waterproofing. The composite is made up of fiberglass which is implied as the base and a coating of mixture of asphalt and limestone over the base. Ceramic granules are sprinkled to the top.

Traditional roofing materials in Pakistan are costly, require periodic replacement and are prione to corrosion. Therefore, these singles are are presented as an alternative to these materials due to relatively lower up-front costs and easy installation.

With the variation in the amount of limestone in the composite, several different samples were tested according to ASTM standards. According to these standards, it is safe to say that as the amount of limestone increased, the strength, waterproofing, tear resistance, fire proofing and wind resistance increased.

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CHAPTER 1

INTRODUCTION

1.1 STATEMENT OF PROBLEM

The materials being used for protecting roofs in Pakistan are brittle in nature, prone to corrosion, require periodic replacement and are expensive.

1.2 ROOF SHINGLES

Roof shingles are a covering over the roofs for providing protection and aesthetics. There are several different types of shingles including wood shingles, asphalt shingles and slate shingles. Asphalt roof shingles are most widely used owing to their comparatively less costs, ease in installation and long life. Due to these advantages, they are being used in over 80% of the houses in United States of America.

Figure 1: Asphalt roof shingles on a house in USA[1]

1.3 CONCEPT

Shingles can be made from different materials. Red cedar is used to make wood shingles, chemically treated new growth trees are employed for modern shingles and Aluminum for Aluminum shingles.

Asphalt roof shingles are one of the most employed roof systems. Their base consists of either fiberglass or organic materials onto which a layer of asphalt with additives is coated.

Further layer of asphalt is again applied and lastly granules are sprinkled over to provide protection against UV radiations and prevent photo-oxidation of asphalt[2].

Major properties of Asphalt roof shingles include, but not restricted to, are their versatility, economically feasible, little maintenance, excellent protection from weather and sunlight, and easy installation.

"Each year 100 million squares of asphalt shingles are used in the U.S. That's an area about the size of Lake Tahoe" [1].

In 1915, Fred Overbury invented the three-tab asphalt strip shingles. It had two grooves whereby the exposed face of the shingle was divided into three sections. Today, residential roofs use more asphalt shingles than any other roofing material. Two of the major reasons for employing asphalt roof shingles are its wide variety of colors and fire resistance. Moreover, they are less expensive both in terms of installation and purchase [1].

On a clear sunny day, it is highly likely that the asphalt roof shingle can reach up to a temperature of 65°C wherein the asphalt becomes pliable and soft. Under extreme weather conditions such as a thunderstorm, the temperature can drop to 15°C. This process is known as thermal cycling. The shingles must have minimal reaction to thermal cycling if they are to function for a long period of time. Therefore, they can shrink, but lack curling ability and can't lift off the shingles below[3].

Before the introduction of fiberglass roof shingles, organic-fiber mat shingles were employed in areas that had extreme winds. However, since the advent of strong fiberglass shingles, the former are rarely used now.

Architectural or laminated shingles were soon made after the introduction of fiberglass reinforcing mat. These are heavy, solid shingles that have multiple layers to give a more overall textured appearance.

Most shingles weigh around 240lb/sq. However, some weigh around 100 lb more per square, particularly architectural shingles. Three tab shingles, hence, only give a warranty

of 15-20 years. Whereas, architectural shingles typically have a life of 30 to 40 years owing to the increased amount of material used in their manufacturing. This results in the increase of pricing[3].

COMPARISON OF ROOFING MATERIALS

	Asphalt	Wood	Metal	Tile	Slate
Cost/square	$25-$56	$150-$200	$35-$250	$120-$1,000	$350-$700
Installation* cost/square	$65-$125	$130-$160	$35-$400	$100-$300	$250-$450
Approx.** life span/yrs.	15-20	10-40	15-40+	20+	30-100
Weight in lb.	225-385	300-400	50-270	375-1,100	500-1,000
Fire rating	A	B***	A	A	A

*Installation costs vary enormously due to many factors such as local labor rates, time of year, complexity of a house's roof geometry, height of a roof from the ground and complexity of a roofing material's profile.

**Roofing materials' life spans are courtesy of the American Society of Home Inspectors.

***Wood shingles and shakes treated with a fire retardant are given a Class B fire rating. Untreated shakes and shingles have no fire rating. A Class A roof is attainable with wood roofing, but a special installation procedure involving a sheathing sandwich made of plywood and gypsum board is necessary.

Figure 2: Roofing materials and their costs [1]

It is worth mentioning here that although testing on shingles are mostly based on weight degradation, the quality of the base materials are a much better indication to their performance. Therefore, it is much more difficult to give the exact quality to the customers. Furthermore, it is necessary to have the fiberglass-mat shingle pass ASTM D6432 which gives the measurement of tear strength. This, in turn, depicts the resistance to cracking and toughness of the shingle.

Figure 2 shows the comparative analysis of cost and properties of the different roofing materials being employed in USA[3].

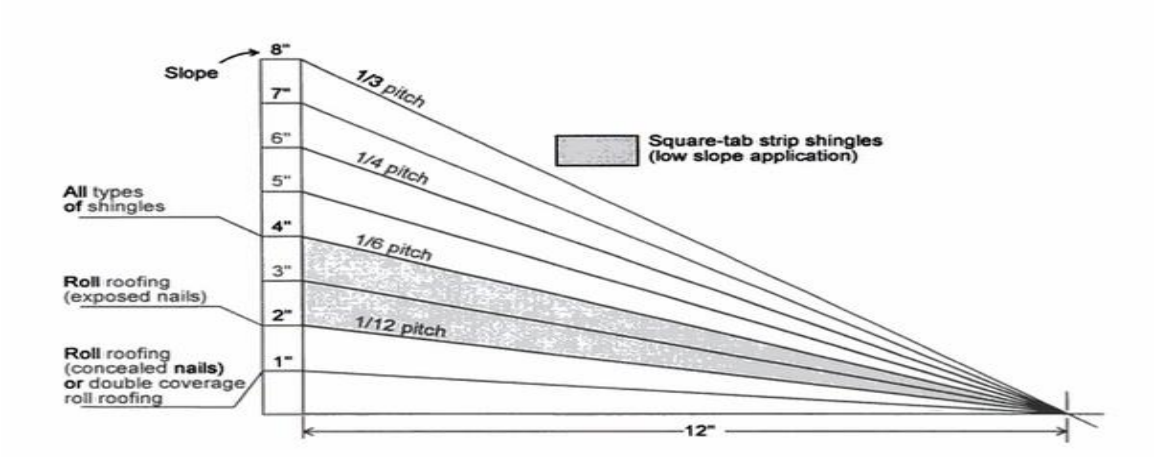

Figure 3: Minimum pitch and slope requirements for various asphalt roof products [1]

The optimum temperature for installing roof shingles are from 4°C to 40°C. However, when installing in cool conditions, it is necessary to lay them in the sun whereas they must already have been stored in a warm location. Refer to figure 3 for roof pitch and the type of shingles that can be employed [4].

Figure 4 shows the components of a typical asphalt roof shingle[4].

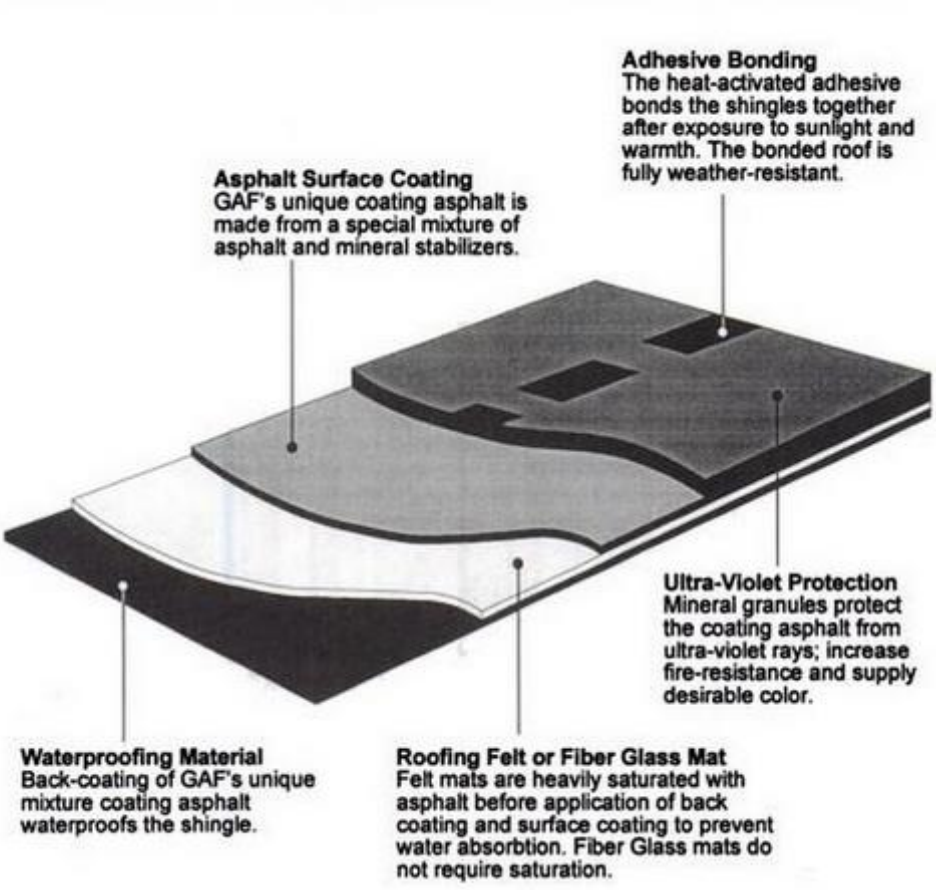

Figure 4: Components of a typical asphalt roof shingles [1]

CHAPTER 2

LITERATURE REVIEW

2.1 TYPES OF ROOF SHINGLES

There are many different types of roof shingles. Figure 2 shows the different properties of roofing shingles. Some of these are discussed below.

2.1.1 FIBERGLASS BASED ASPHALT ROOF SHINGLES

Fiberglass roof shingles employ a base of glass fibers reinforcing mat. This mat has exceptionally high strength and heat resistance. Chloropene based rubber adhesive is applied to the top of this mat. This makes the handling of the randomly oriented fibers easier. Furthermore, a layer of asphalt mixture is coated onto the top.

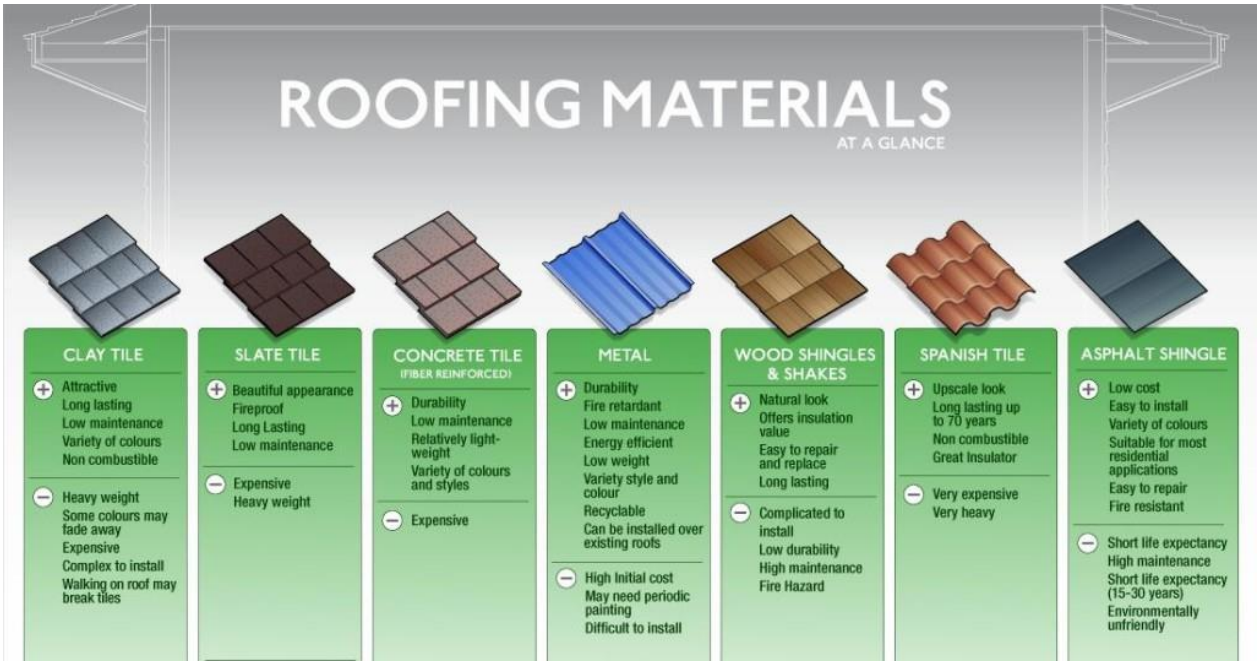

Figure 5: Various types of shingles and their physical parameters

Fiberglass has better fire resistance than organic mats. However, it does not have waterproofing properties which is why additives like mineral fillings are added. It provides reinforcing abilities. Waterproofing is provided by asphalt. However, asphalt does not adhere to the mat itself. Hence fillers are used which stick to the mat and asphalt fills the voids in the mat. In this way, waterproofing is provided. Cooling time is provided to the

mat and another layer of asphalt is coated onto which a layer of ceramic granules are embedded. The end result is a thin and light shingle.

2.1.2 RUBBER BASED ROOF SHINGLES

One of the great alternatives to asphalt shingles are rubber based roof shingles. For keeping the integrity of the look of the home, these shingles mimic the look. They can withstand pests, provider waterproofing, insulation and fire resistance. They are strong and flexible. Rubber was being used from 1950s till onwards by recycling the old rubber into goods including those for roof [5].

These are made by using recycled tires. The process involves removing the tire wall section while different sections of tread section are segmented. Next is the buffing off of actual tread and coating sawdust or slate dust onto the shingles.

2.1.3 ORGANIC SHINGLES

Although the production of organic shingles have halted since 2005, it is necessary to mention them. They declined in popularity due to their lack of competitiveness with fiberglass shingles in terms of life. These are also known as felt mat asphalt shingles. These were portrayed as eco-friendly by the companies. However, no such substantial evidence was provided and hence many companies were sued by the homeowners.

The organic components of the shingles comprised of recycled cardboard, wood chips and rags, and paper. These were saturated with asphalt. In fact, these had more asphalt than fiberglass shingles. Granules are then embedded onto the top surface, hence, protect against UV rays.

2.1.4 SLATE

Slate is the best option for homeowners looking for longest lasting roof materials. It is a naturally occurring rock which is mined and cut into shingles or tiles. Their lifetime is exceptionally high such that there are buildings with over 100 years old slate roofs that are still performing excellently.

There are a number of benefits of slate shingles. Some of these are highlighted below:

1. They have exceptional lifetime, around 80-100 years
2. They are esthetically pleasing
3. It has extremely low water absorption index around 0.4%. It works on both ends of the spectrum i.e under extreme hot temperatures and freezing temperatures.

4. It has high strength and less prone to damage under windy or stormy conditions when compared to asphalt shingles.

There are negative attributes associated to slate shingles as well. Some of these are mentioned below:

1. These are very expensive as compared to other materials such as asphalt shingles.
2. High repairing costs are associated with slate roofs. For instance getting a professional slater will prove to be very expensive.
3. Since these are very heavy, slate roofs are not recommended for structures that lack proper support to the weight.

2.1.5 SOLAR SHINGLES

One of the latest breakthroughs in the construction industries is the introduction of solar roofs that provide protection along with generation of energy [3].Several different patents have been made due to ever increasing demand of energy. Moreover, this has the potential to take the home off the grid, thereby, providing creative solutions to the existing energy crisis [6].

2.1.6 METAL ROOFS

These are designed for either steep or flat roofline [6]. The metals that are employed range from solid metals to constructed metal. The price ranges from very cheap to very expensive. For example, a low-galvanized metal will cost very less. Moreover, these can last over 50 years and are becoming very popular.

2.2 ASPHALT ROOF SHINGLES

2.2.1 WHY ASPHALT ROOF SHINGLES?

Fiberglass shingles do not contain as much asphalt as organic shingles do. The base is a fiberglass held together by resins or adhesives. The reason for using fiberglass is due to its strength and fire resistance. Mat is coated with asphalt which is filled with mineral fillers making it waterproof [6].

These are not very ideal for cold climates as fiberglass becomes brittle and, therefore, can break. However, organic asphalt shingles used be used instead owing to better performance in windy and frigid climates.

However, fiberglass shingles are better employed in hot climates due to high heat resistance. Since these have higher alkaline nature, they are prone to algae attack [7]. Henceforth, a dirty appearance is evident. This in turn reduces the ability to protect against the sun's rays. Thereby, increasing the costs as the house would be warmer.

The total difference between the fiberglass and organic shingles lies in the use of fiberglass in the former and organic base in the latter. Fiberglass shingles absorb less moisture and are more resistant to heat. Therefore, these have higher durability in warm climates.

2.2.2 WHY USE FIBERGLASS?

The major reasons for using fiberglass are:

1. Cost effective
2. Less weight
3. Longer wear life
4. Better fire rating
5. Thinner

2.3 ADVANTAGES

There are many benefits to asphalt roof shingles. These include, but are not limited to:

i. COST EFFECTIVE

Asphalt roof shingles are very cost effective.

ii. EASY MAINTENANCE

Shingles are low maintenance roofing materials. These are easily applied to the roofs either by drilling or applying adhesive to the under-layer. Moreover, in case of the need to replace shingles, a moderately experienced person can also replace them.

iii. DURABLE

Thermal shocks are deadly to the shingles. This happens when there is a sudden change in the temperature within a very short span of time. To extend the service life of shingles, it is important to have proper ventilation in the roof.

iv. LONG LIFETIME

The lifetime of shingles depends on the environment in which they are installed [4]. A comparatively cooler climate will sustain shingles far longer than the ones in the warmer climate. Several different types of ASTM Standards are followed in order to ascertain the average life of shingles. One of the most important tests carried out is thermal shock. This is done for a very short period of time mostly 24 hours [8].

vii. RECYCLABLE

Asphalt roof shingles are not harmful to the environment such that they are used in Roof-to-Road projects. In these the roofs shingles are recycled and then used for pavement construction [4].

viii. AESTHETICALLY PLEASING

There are over 50 shades of shingles currently in the market. Therefore, not only are these more attractive, but also cost effective**.**

2.4 COMPOSITION OF SHINGLES

The major components of asphalt shingles are:

1. Fiberglass Mat
2. Asphalt
3. Ceramic Granules

Fiberglass asphalt shingles have fiberglass as the base onto which the adhesive is applied. After some time, asphalt mixture consisting of additives is applied and a ceramic granules layer is sprinkled on the top. These protect the shingles from Ultra-violet radiations of the sun and prevent photo-oxidation of asphalt. However, it is to be mentioned here that using very fine and expensive inhibitors would, of course, increase the cost of the product. Therefore, economical factors need to be taken into account [9].

2.5 PROBLEMSWITH ROOF SHINGLES AND THEIR REMEDIES

i. THERMAL SHOCK

One of the major drawbacks of shingles is thermal shock. They are not able to contract or expand under extreme conditions when temperature drastically changes in a short span of time. Therefore, cracks and splits appear in the material. Water then seeps into the material. It damages the structure in two ways:

- Water gets into the cracks and freezes at night. Since water expands on cooling, the frozen water expands and causes splits in the structure.
- There is an indirect method of water damage. In general, water doesn't hurt asphalt directly. However, it encourages the growth of fungus and algae.

Proper type of shingles should be employed for the specific slope. It must be remembered that steeper pitches should have longer shingles. Moreover, it is necessary to have standardized testing of the shingles as well as the roofs.

ii. BLISTERING

Elevated sections on shingles are known as blisters. These are caused by different factors. Mostly these are part of the aging process. However, if these are new, they are most probably manufacturer's defects [5]. These may also be caused by poor ventilation.Proper ventilation would get rid of this problem.

iii. RAISED SHINGLES

Raised shingles are caused by improper installation. These are not strong enough to resist wind uplift. To get rid of this problem, it is necessary to hire licensed and certified for roof replacement of repair.

iv. GRANULE LOSS

Granules loss is one of the major signals to indicate the end of life of shingles. However, at times, it occurs due to premature deterioration. Getting in touch with the manufacturer would solve this issue as it may have risen due to fault in the manufacturing processes [5].

2.6 ASPHALT SHINGLES IN PAKISTAN INDUSTRY

There is a huge market for shingles in Pakistan's industry. Currently there is no industry in Pakistan, but if attention is paid towards this sector then a lot of benefits can be gained by both the people and the investors.

CHAPTER 3

EXPERIMENTAL METHODOLOGY

3.1 RAW MATERIALS

The raw materials used for manufacturing asphalt roof shingles are[10]:

Table 1: Raw Materals used in Asphalt shingles

Sr.No.	Material
1.	Fiberglass Mat
2.	Asphalt
3.	Adhesive
4.	Kerosene Oil
5.	Mineral Granules
6.	Sand
7.	Limestone

Three different types of samples with compositional variation were made. In each of the sample of asphalt was used. Table 1 shows the different raw materials.

3.2 PROPERTIES OF MATERIALS USED

3.2.1 FIBERGLASS MAT

Extremely fine fibers of glass are woven together to give high strength to structure. Properties of fiberglass mat are:

i. DIMENSIONAL STABILITY

It is well known that fiberglass neither stretches nor shrinks. The nominal elongation break for fiberglass is only 3-4 percent.

ii. GOOD THERMAL PROPERTIES

Low coefficient of thermal expansion is associated with fiberglass.It also has relatively high thermal conductivity.

iii. HIGH TENSILE STRENGTH

It has high strength-to-weight ratio. It can be understood by the fact that it is twice as strong as steel wire.

iv. ELECTRICAL INSULATION

Fiberglass has fantastic electrical insulation due to relatively low dielectrical constant and high dielectric strength. Moreover, it also provides thermal insulation [8].

v. LOW MOISTURE ABSORPTION

It absorbs very low moisture content [4]

vi. CHEMICAL RESISTANCE

It does not deteriorate nor does it rot. Only hydrofluoric acid and phosphoric acid can effect fiberglass [5].Otherwise it is resistant to most acid attacks [9].

vii. HIGH THERMAL ENDURANCE

It is unaffected by curing temperatures which are mostly being used in industrial processes and nor does it burn. It can be better understood by observing its behavior at 700°F and 1000°F. Under former conditions, it retains around 50% of its strength and under latter conditions, it retains 25% of its strength.

viii. COST EFFECTIVE

When compared to other natural and synthetic fiber fabrics, it offers a more cost effective product [9].

ix. PRODUCT VERSATILITY

There is a broad range of fiberglass parameters being offered in the market. For instance, different yarn sizes and weave typesare available [5].

3.2.1.2 TYPES OF FIBERGLASS

Different types of fiberglass are listed in Table 2.

The most commonly used fiberglass is E-Glass. It is a alumino-borosilicate glass having less than 1 wt% alkali oxide. One of its major applications is in glass-reinforced plastics.

Table 2: Types of fiberglass

Sr.No.	Type
1.	A-Glass
2.	E-CR Glass
3.	D-Glass
4.	S-Glass
5.	E-Glass
6.	C-Glass
7.	R-Glass

A-Glass is an alkali-lime glass with minimal boron oxide.

C-Glass is an alkali-lime glass with high percentage of boron oxide. It is majorly used for glass staple fibers.

E-CR Glass is Alumino-lime silicate glass with less than 1 wt% alkali oxides. It has high acid resistance.

D-Glass is borosilicate glass having high dielectric constant.

S-Glass is Alumino silicate glass with no Cao, but high percentage of MgO. One of its major advantages is high tensile strength.

R-Glass is Alumino silicate glass with no MgO or CaO. It has high mechanical requirements.

3.2.1.3 SAFETY

One of the major reasons of switching from asbestos to fiberglass was the fact that asbestos caused cancer [5].However, a few researches have shown that fiberglass also causes similar toxicity as asbestos. This may be due to both having silicate fibers [10].

While working with Fiberglass it is necessary to protect the body from the fibers such that these can penetrate into bare skin. When these are either scratched or rubbed, the fibers dig deeper into the skin and can cause injuries [10].

3.2.2 ASPHALT

The crudest form of petroleum is Asphalt. Its appearance is black and sticky. It is a highly viscous or semi-solid. Primarily, it is used in road construction where particles are glued or bound together by it. Asphalt is a mixture of mineral aggregates [7].

Extraction of asphalt takes place through fractional distillation under vacuum conditions. In this way it is separated by other components found in crude oil such as petrol, naphtha and gasoline. Further processing is carried out in asphalting unit wherein either supercritical phase of propane or butane is used to dissolve lighter molecules. Finally, blowing is done wherein the product is reacted to oxygen thereby making it harder and more viscous [7].

3.2.3 ADHESIVE

A rubber base contact adhesive improves the overall wetabbility of asphalt over fiberglass along with improving the base strength.

3.2.4 KEROSENE OIL

One of the major issues that arose during sample preparation was quick solidification of asphalt as soon as it was applied. To overcome this issue, 10% by volume of kerosene was added into the asphalt mixture. This in turn allowed more time for asphalt to cool down. Therefore, application of asphalt became easier [7].s

3.2.5 MINERAL GRANULES

It is necessary to coat the top layer of the asphalt. It can either be marbles coated with ceramics or simple marbles. However, in our project we have used marble stones which are excellent against UV light of the sun [11].This is dangerous becauseUV light can cause photo-oxidation of asphalt thereby rendering the whole structure useless. Moreover, the biggest advantage of using ceramics is its wide variety of colors. Not only are these esthetically pleasing, but also increase the resistance to fire [12]

3.2.6 SAND

Sand is used for coating the under-layer of the fiberglass [7].This provides better adhesion and protection to the overall structure [13]

3.2.7 LIMESTONE

Limestone is added as a filler to the asphalt mixture [6].Asphalt coating contains 50-70% of limestone by weight. The primary motivation for using limestone is its immediate effect on cost lowering, increased durability and reduction in amount of asphalt [14]

3.3 SAMPLE PREPARATION

3.3.1 COMPOSITION OF ASPHALT SHINGLES

The composition of asphalt shingles is listed in table 3.

Table 3: Composition of materials used in samples

Sr. No.	Material	Composition by Weight %
1.	Fiberglass	5
2.	Asphalt with Limestone	75
3.	Sand	10
4.	Adhesive	10

3.3.2 PROCESS FLOW

The process takes place in the following way:

i. Base Formation
ii. Application of Asphalt Mixture
iii. Coating of Upper Surface
iv. Coating of the Back Surface

3.3.3 BASE FORMATION

For base formation, fiberglass was coated with adhesive on both sides [5].This was done with the help of brush. It is important to note that after the application of adhesive, it should be put into either water or kerosene oil so that it doesn't stick to the hair of the brush [7]

3.3.4 APPLICATION OF ASPHALT MIXTURE

After the application of the adhesive, a relatively stronger fiberglass is formed.

Asphalt is heated to 180°C for two hours [6]. 10% by volume of kerosene is added to asphalt. The required amount of limestone is added to prepare several samples. This mixture is then applied to the top of the fiberglass and left for some time until it sets in [7].

3.3.5 COATING OF UPPER SURFACE

Marble is sprinkled onto the top as soon as the asphalt mixture sets in a little bit. This provides temperature resistance and protection from UV light of sun [6]. Crushed chips of marble were used in the process because they are easily available in the market [15]

Three types of samples were prepared by varying the composition of Limestone in Asphalt. This is shown in Table 4.

Table 4: Variation of Limestone

Sr. No.	Sample Type	% Limestone in Asphalt
1.	A	15
2.	B	10
3.	C	5

3.3.6 COATING OF BACK SURFACE

Back surface was prepared by first applying adhesive and after 30 seconds sand was sprinkled onto the back by a sieve. At the end of the process, the shingle was ready to be utilized [7].

Figure 6 shows the sample preparation methodology. Refer to Figure 7 for proposed mechanized process for fabricating roof shingles.

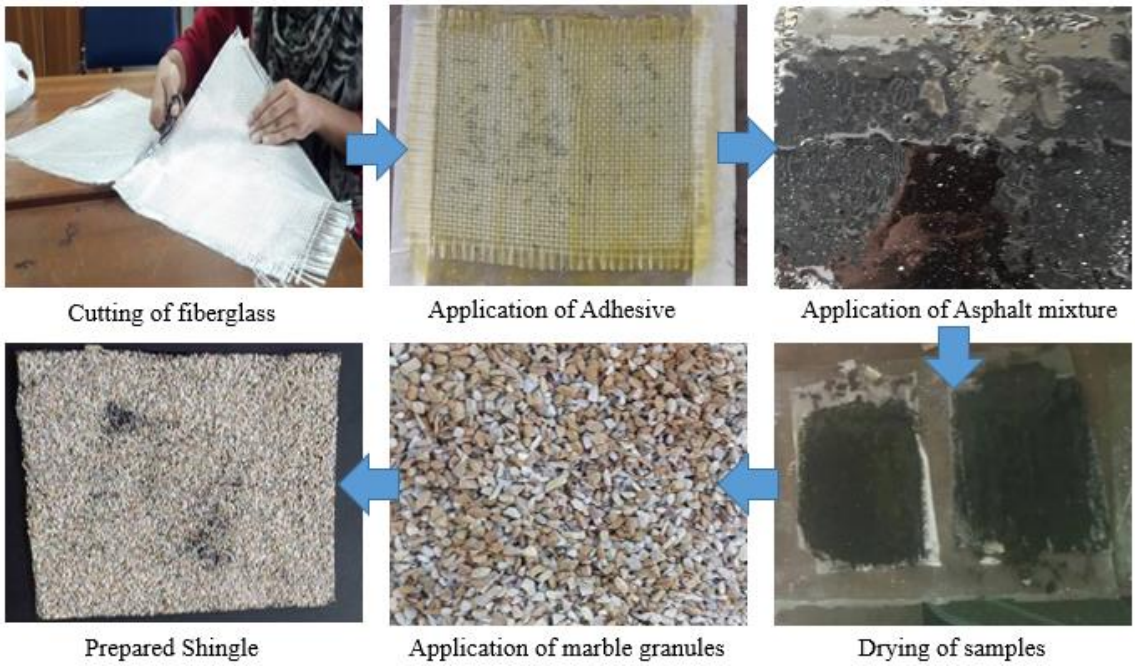

Figure 6: Preparation of Samples

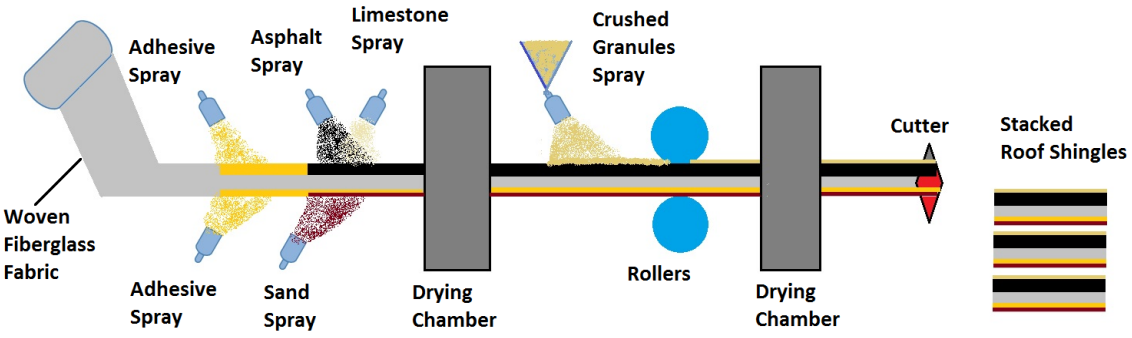

Figure 7: Mechanized process flow diagram

3.4 EXPERIMENTATION

The tests that were carried out are listed in the Table 5.

Table 5: Various tests conducted

Sr. No.	Test	ASTM Standard
1.	Tensile Strength Test	D4073-06
2.	Tear Resistance Test	D1922-15
3.	Water Abrasion test	D1079
4.	Wind Resistance Test	D3161/D3161M-16a
5.	Fire Test	D-228

3.4.1 TENSILE STRENGTH TEST

3.4.1.1 SCOPE

"This test covers the determination of tensilestrength of bituminous membranes."

Maximum load is measured when the specific dimensional specimen is tested to failure at an arbitrary and fixed tensile strain rate.

3.4.1.2 APPARATUS

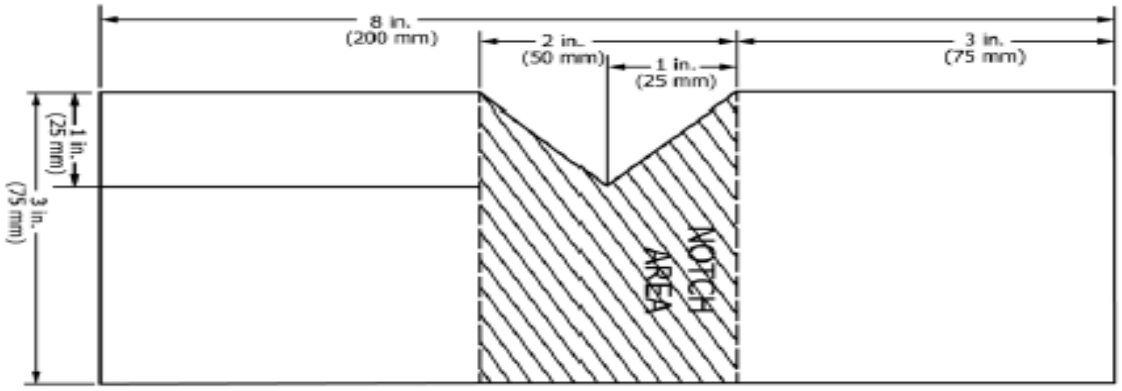

Figure 8: Tensile strength sample dimensions

a. MACHINE

Universal Testing Machine was used to evaluate the strength of the samples. It is necessary to have an automatic load and strain recording system. Cross-head movement was kept to 2.54 mm/min [16].

b. GRIPS

Jaw faces of grips was 75mm wide by 50mm deep. Uniform clamping pressure was provided so that the specimen does not slip.

3.4.1.3 SAMPLING

Temperature was kept at 39 ± 2°C. The dimensions of the sample were 300 by 500 mm. The sample was prepared according to the diagram shown in Figure 8.

3.4.1.4 PROCEDURE

The specimen was prepared by cutting through the fiberglass at dimensions of 300 by 500mm. It is worth mentioning here that the fiberglass is first cut and then the shingle is prepared.

The jaws of the self-aligning grips were set 100mm apart. The specimen was clamped in the jaws such that jaw faces cover 75mm wide by 50mm deep area of specimen at each end.

The specimen was broken at constant rate of cross-head movement of 2.54 mm/min. Maximum load in pounds-force (Newton) was recorded as the conclusive result.

The specifications of the machine used are:

Universal Testing Machine, model: AG-X Plus (Shimadzu).

Load Capacity: 20kN. Strain Rate: 0.0005-1000.0 mm/min.

3.4.2 TEAR RESISTANCE TEST

3.4.2.1 SCOPE

Average force to propagate tearing through a specified length is determined by this test. Two samples are used among which one of them would be referee specimen and the other will be the one with constant radius testing length.[11]

The ASTM standard being replicated here is D3161/D3161M-16a.

3.4.2.2 APPARATUS

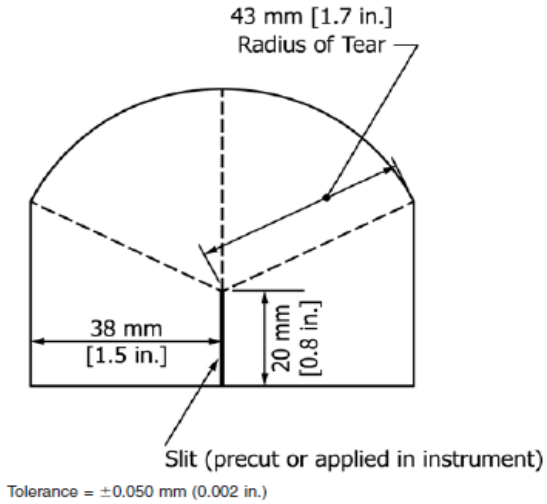

Figure 9: Tear resistance sample dimensions

a. Machine

UTS machine was used to perform this test.

3.4.2.3 SAMPLING

Test specimen was cut to form a rectangle with dimensions 76mm width by 63mm length. The latter dimension will be the direction of tear. A slit of 20mm is made at the center of the specimen leaving behind 43mm of length at the ends of slit and specimen's opposite edge.

3.4.2.4 PROCEDURE

Test was performed at room temperature which was at the time 38 ± 2°C. The specimen was placed in the machine wherein the jaws gripped the opposite ends. It was ripped at 2.54mm/min. The end results were recorded and tabulated in the table.

3.4.3 WIND RESISTANCE TEST

3.4.3.1 SCOPE

Wind resistance is evaluated for roof shingles. The test samples were attached to the surface using adhesive wherein the slope was kept at 38°.

A fan was used to induce a stream of air across the exposed specimen surfaces. No uplift resistance is measured using this method. Therefore, this is not recommended for membranes or metal roof panels.

3.4.3.2 CLASSES OF STEEP SLOPE ROOFING PRODUCTS

Class A- Velocity of 60 mph

Class D- Velocity of 90 mph

Class F- Velocity of 110 mph

3.4.3.3 SIGNIFICANCE

This test provides results that are nearly similar to the behavior of shingles in the natural conditions. However, it is to be noted that these conditions vary in terms of turbulence, duration and intensity.

3.4.3.4 APPARATUS

Test Machine: Fan capable of delivering horizontal stream of air through a circular opening with wind speed of 60 mph. It is worth mentioning here that the test was conducted only for class A.

Specifications of the fan: 24” in size. Volts: AC 240 and Watt: 150. RPM: 1500 with air delivery 187 m^3/min.

3.4.3.5 TEST SAMPLES

The dimensions of the samples was kept to 15cm by 8cm. Testing was performed on nine samples wherein three replicates of three compositions were used. These samples were then attached to a sloping panel kept at 28° by use of adhesive. . Total time for the test was 15 hours. Temperature was kept at 28 ± 2°.

3.4.4 FIRE TEST

3.4.4.1 SCOPE

Samples are tested based on extreme conditions. This is to mimic the natural conditions of environment in which shingles are to work.

3.4.4.2 APPARATUS

Samples are placed in the oven for a period of 18 hours at 80°C. Samples of approximately 8cmX8cm were cut and placed in the oven. After 2 hours, the samples were weighed and observed for any change in the appearance such as blisters or absorption of asphalt coating. Moreover, this could include change in color and sliding of coating among other deformations.

3.4.5 WATER ABRASION TEST

3.4.5.1. SCOPE

Samples are tested for water resistance under controlled conditions. This is to check shingles' behavior under moist conditions since seepage throught the roof is a common effect of rain.

3.4.5.2. APPARATUS

Samples are placed under running water having different rate of flow. Samples were of 8cmx8cm and their weight loss by water was measured. Change in the top most layer due to water flow was also studied.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 TENSILE STRENGTH TEST

The tensile strength of the three compositions was analyzed. There was little variation in the strength within the individual set of sample composition. This may be due to difference in the deposition of asphalt since hand layup process was used to make the samples.

From the three sample, it is clear that the sample A has the highest strength whereas sample C has the lowest strength. This is due to the increased amount of limestone in sample A as compared to sample C. As limestone provides better binding properties as well as increased strength, it is no surprise that the samples with greater composition of limestone have depicted more strength. However, it is worth noting here that there is a drastic difference between sample B and C as compared to A. This is due to closer percentage of limestone between sample B and C due to which there isn't significant difference between the two.

Conclusively, the overall strength of composite is due to the base material i.e. fiberglass mat and the stress-strain curve of sample without any coating on it is shown in Figure 10.

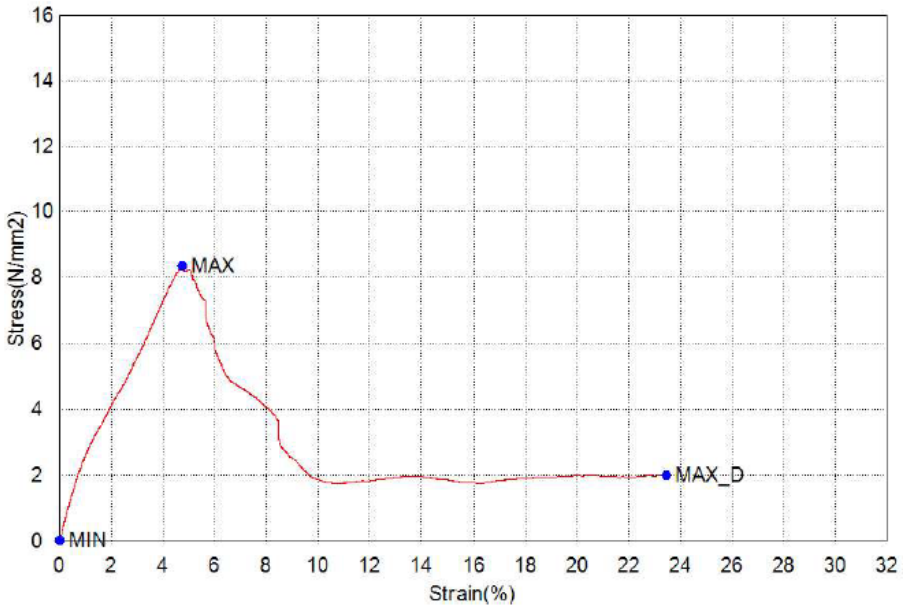

Figure 10: Stress-Strain Curve Fiberglass based Asphalt Shingle

4.2 TEAR RESISTANCE TEST

The tear resistance of the three compositions were analyzed. A slight difference in the tear resistance was observed and the sample with the maximum amount of limestone showed the maximum tear resistance. However, the major contribution in tear resistance is of fiberglass mat as shown in the Figure 11.

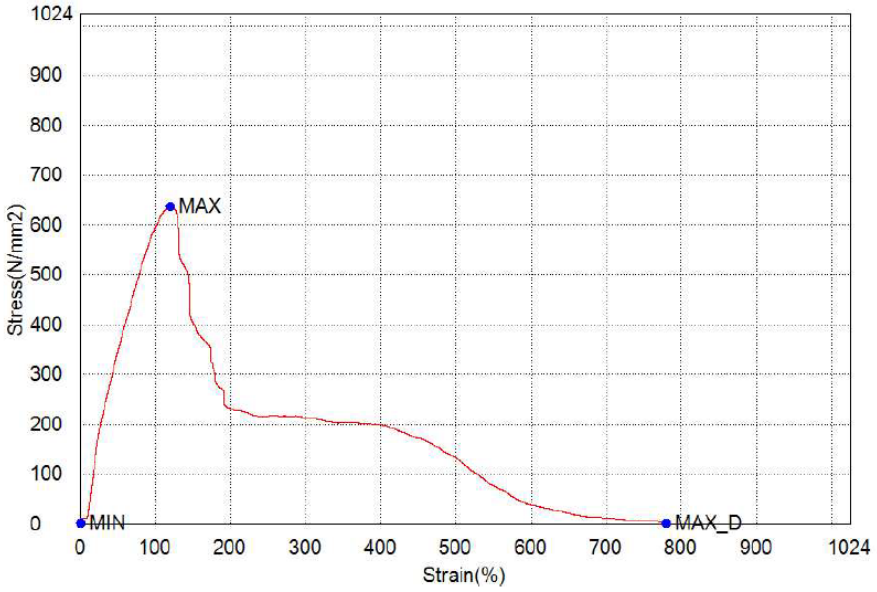

Figure 11: Stress-Strain Curve Fiberglass based Asphalt Shingle (Tear Sample)

Three different samples of each composition, hence a total of nine, were prepared for this test. It is evident from the figures that sample A has the highest tear resistance whereas sample C has the lowest resistance.

Again, this slight change in strength is due to the filler, that is, limestone. It is worth mentioning here again that the major strength contribution is of fiberglass and amount of asphalt being used in all the samples same, therefore, the effecting factor is limestone only.

4.3 FIRE TEST

Fire test was carried out at four different temperatures. This can be seen on Table 4. The degradation of shingles mass was measured. The samples were weighed and masses noted. The average masses of samples A, B and C are 88.75g, 88.64g and 84.23g , respectively.
Refer to Table 6 to understand the test results. It can be seen that all samples passed the test at -15°C and 50°C with minimal difference in the weight loss.
However, when the temperature was increased to 60°C, the degradation of sample C was most prominent whereas sample B also lost some of its mass. Moreover, at 80°C the sample with the best results was Sample A. This is due to compositional variation of limestone which provides better adhesion at higher concentration. Therefore, asphalt doesn't leave the structure and sample mass loss is least.
Furthermore, it can be seen that sample C at 60°C and 80°C shows anomaly. This may be due to uneven sample preparation as hand lay up process was used. However, by literature review and other testing, we can easily conclude that it doesn't have a pronounced effect. Therefore, this doesn't affect the end results too significantly.
Conclusively, sample A, which has the highest percentage of limestone, is the best sample among all the rest.

Table 6: Comparative analysis of fire test results

Sr. No.	Sample (refer to table 4)	15°C (% weight loss)	50°C (% weight loss)	60°C (% weight loss)	80°C (% weight loss)
1.	A	0.022	0.016	0.022	0.022
2.	B	0.057	0.285	1.141	0.570
3.	C	1.187	2.137	4.986	3.51

4.4 WIND RESISTANCE TEST

Various samples at 28° inclination were subjected to high speed winds of 60mph and 90mph. The masses of each samples were equal to the ones stated in Fire Test.

All samples sustained at 60mph. However, at 90mph, sample C rapidly degraded and bonding with the base roof was disrupted. Similar behavior was shown by sample B. However, it was at much less intensity than Sample B.

Furthermore, sample A, not only sustained 60mph, but also 90mph. Therefore, it can easily be concluded that as the amount of limestone increases, the strength gets increased. This results in lower loss of mass of shingles.

Conclusively, sample A has shown the best behavior with minimal loss of mass.

Table 7: Comparative analysis of wind test results

Sr. No.	Sample	60 mph (% weight loss)	90mph (% weight loss)
1.	A	0.005	0.009
2.	B	0.034	0.10
3.	C	1.430	1.861

4.5 WATER ABRASION TEST

Water abrasion test was performed to obtain the behaviour of test samples under wet conditions. 9 different samples werre placed as described under the water abrasion test section. The results obtianed are tabulated below.

Sample A showed the best results. Its composition and structure was not even disturbed. As compared to A, B showed slight mass loss and also the upper most granule coated layer was damaged. Sample C which had the minimum amount of limestone showed comparatively larger damage and more weight loss via this test. Through water abrasion test, we concluded that the composition of sample A showed the best results and should be used for producing long lasting water proof shingles which are comparatively corrosion proof.

Table 8: Water abrasion test results

Sr. No.	***Sample***	***Mass loss***
1.	A	0.020
2.	B	0.028
3.	C	0.125

CONCLUSIONS

Five different tests were conducted to characterize the various compositions of the asphalt roof shingles. Sample A had the highest amount of limestonei.e 15% by mass, Sample B had 10% whereas sample C had the leat amounti.e 5% by mass. Owing to the difference in the composition of limestone, the properties of samples changed.

Tensile strength showed that the major strength is provided by the base material i.e. fiberglass. However, very minute changes were seen by varying the compositions of limestone. The sample with the most amount of limestone is rated as better as compared to others. Therefore, sample A showed that maximum amount of tensile strength. Tear strength also showed almost the same result.

Fire test also showed that the amount of limestone has immediate effect on the properites of shingles. Therefore, Sample A exhibited less than 0.02gmass loss under all four temperatures i.e 15°C, 50°C, 60°C and 80° whereas sample C had the most disintegration with 12g mass loss at 60°C.

Wind test also provided the information regarding the behavior of shingle under windy conditons. Sample A passed the test at 60mph and 90mph with less than 0.01g massloss whereas Sample B and C lost approximately 1g and 2g, respectively.

Furthermore, it was again proved right owing to the test results shown by water abrasion test wherein the sample A did not disintegrate nor the top coating wore off with a mass loss of only 0.018g. Therefore, sample B and C were of inferior quality as compared to sample A with mass losses 0.025g and 0.106g, respectively.

Conclusively, it is safe to say that as the amount of limestone increases in shingles, the strucuture becomes more credible and stronger, therefore, sample A is concluded to be the best among the three compositions.

RECOMMENDATIONS

It is recommended that several different types of ceramics be coated onto the top surface so as to increase its aesthetics. Ceramics give various colors to shingles and also protect from radiations from sun.

Since shingles are apart of green buildings, it is further recommended to include solar panels on top of the surface such that it not only protects the roof, but also provides electricity.

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