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Multiple Applications Rubber Tiles & Their Composite Materials Formulations Using Recycled Rubber

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Abstract - *This research investigates the production of flexible rubber powder tiles using tire waste in addition to polyurethane resin as a binder. The material is an eco-friendly solution to a growing problem in the world, rubber tires are mostly discarded or burned to extract their reinforced steel wires instead of being properly recycled. The results of this research can be considered as a way of recovering rubber waste. Various trials of experimental work that were carried out and are explained in details. Different particle size distributions, rubber contents, and tests were examined and then tested. Characterization analysis of tensile, compression, hardness, and aging tests were carried out to evaluate the composites. The results conclude that the amount of rubber used is too large compared to the resin, which increases the percentage of rubber in the formulations, thus using more recycled waste. The benefits of waste rubber composites are that they are an inexpensive, lightweight, and economical solution for waste rubber disposal. Rubber composites led to their use in energy absorption and thermal insulation. The flexible characteristics of the resin and rubber blend allow these composites to be used in a variety of applications. Results clarified that the composite can work very well for various applications, such as soft floors and barriers.*

Key Words: Rubber tiles, recycling process, composite material, polyurethane resin, flexible rubber powder, and vulcanized rubber.

1. INTRODUCTION & LITERATURE REVIEW

Due to the expansion in manufacturing of vehicles and the significant increase in the numbers of scrap tires in landfills, which consumes lots of space and endanger the nearby inhabitants due to the environmental hazards of the tires landfill. This fact initiated the need to get rid of the scrap tires in the most efficient way which led to the recycling of rubber [1].

1.1 Recycling Overview

Recycling is the process of collecting and processing materials that would otherwise be discarded like garbage and turning them into new products. It is challenging to find ways to produce more energy and reduce waste production while minimizing limited natural resources [2].

Every year, worldwide, 1.6 billion new tires and around 1 billion used tires are produced. However, the recycling industry only processes 100 million tires per year [3]. This fact explains the size of the problem and clarifies that there has to be a quick and effective step in order to solve this problem for both environmental and economic reasons.

1.2 History of Rubber Recycling

Scrap tires have been recycled for nearly a century, but the market has grown significantly over the past two decades due to the increase in applications that have led to the innovation in manufacturing currently shown. Recycling of waste rubber has been done to some extent by the rubber industry almost from its inception, and the first commercial activities in rubber recycling, by reclaiming, began not long after vulcanization was developed. Recycling rubber through the production of recycled rubber was of sufficient commercial interest in the 19th century for the development of three different types of remedial procedures. **Figure 1** shows part of the rubber recycling process.

Although most tires and tire waste are produced in China with about 60% of the total world production [4]. In the United States and Europe, new problems are emerging in developing countries, such as poor management of waste and obsolete technologies, weak environmental policies, and social problems (such as illegal tire burning) [5].

Figure 1: Rubber recycling process

Various researches were carried out to study the manufacturing of rubber tiles, their composites, and their properties.

Paulina Kosmela, Adam Olszewski, et al. concluded that the compressive and tensile performance of composites filled with waste oil-modified ground tire rubber was almost the same as for the unfilled foam. They emphasize the need for compatibilization of these materials by the enhancement of interfacial interactions between the polyurethane matrix and rubber filler phase, which significantly affects the performance properties of prepared materials [6]. Khalil Ahmed, Nudrat Riza, et al. developed natural rubber reinforced with marble sludge by compression [7]. Chan Wen Shan, Maizlinda Izwana Idris, et al. showed that the interactions and the properties of foams of polyurethane with coconut coir fibers and recycled waste tires are presented [8]. Shahruddin Mahzan, I. Maznan, et al. studied polyurethane foams that contain various fillers of Kenaf fibers and rubber particles contained in recycled tires [9].

Tire rubber was also used in construction works. Diego Orlando, Daniella Mulinari, et al. analyze the feasibility of using waste rubber tires that are reinforced with polyurethane (PU) foam obtained from castor oil to gain composites [10]. Xin Xiao, Jiayu Wang, et al. innovate a mixture of waste ties rubber thermoplastic polyurethane resin with a higher elastic modulus that using as a water-resistant material for high-speed railway structures [11].

In Egypt, tire data was reported at 6,584.000 units in 2016. This is an increase from the previous number of 6,520.500 for 2015. Industrial production in Egypt: tire data is updated every year, with an average of 1,315.000 units from June 1992 to 2016, with 25 observations. Data hit an all-time high of 6,584.000 units in 2016 and a historic low of 1,072.800 units in 2002. Industrial production in Egypt: data on tires are reported by the Ministry of Planning. The data is classified in Egypt by Global Database - Table EG. B005: Industrial production: annual [12]. **Chart 1** shows tires industrial production in Egypt from 1992 to 2016.

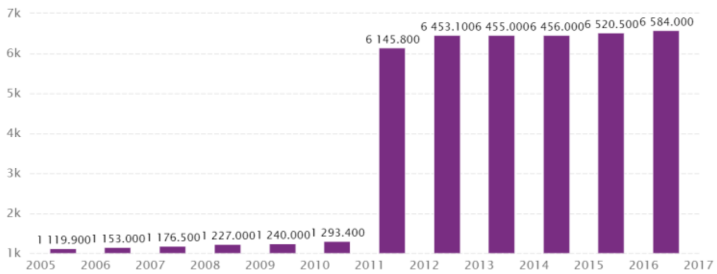

Chart 1: Tires industrial production in Egypt from 1992 to 2016

Traveling along Cairo's ring road or through one of its many poorer suburbs, one often encounters the pronounced smell of burnt rubber: we regularly see piles of rubbish burning on the sides of the roads. Egypt creates 80 million waste tires a year and only 10% of them are recycled. Only a few sophisticated tire recyclers exist in Egypt, including Italian-Egyptian company 'Egitco' in Alexandria and a factory named 'Abdulwahhab for tire and rubber recycling', alongside small workshops where tires are reworked manually [13].

After reviewing most possible solutions to reduce the waste of rubber tires, and most of the applications used to reduce the impact of this problem on the environment. Most of the previous researches in this field used additional percentages of natural rubber, but this resulted in an obvious increase of the cost. Previous researches also showed that only one size of rubber granules is used, but this had a negative effect on the mechanical properties. Therefore, the decision was taken in this research to produce a mixture of rubber granules of different sizes without adding any percentage of natural rubber. Many experiments were carried out before starting to reach the equitable and homogeneous ratios, the appropriate temperature, and the ideal pressing time and force. This is discussed and explained in the work methodology and shown in the results.

2. WORK METHODOLOGY:

Four different sizes of rubber granules are used in this research: mesh 30 (0.595 mm), mesh 20 (0.841 mm), mesh 10 (2 mm), and mesh 5 (4 mm). These meshes were obtained after removing steel and any metallic contents from recycled tires. The tires were shredded using a rotary shear shredder machine that crushes with two counter-rotating barbs at high torque and low speed, it breaks the samples into smaller pieces of size around 15 cm^2. Square blocks were entered into the roll crushers to settle the incomplete parts in the first stage and then entered a second stage to sort the rubber granules well. Then, as a final stage, these finely ground granules with a good texture were entered into an industrial vibrator that contains three grids of different pores in order to sort out the different sizes.

2.1 Problem Formulation

Previous researches were carried out to investigate recycling or rubber tires using only one size of rubber granules in the base mixture and many of them also added an amount of natural rubber which increases the cost. However; in this research, different compositions consisting of a mixture of different sizes were used in order to improve the extent of the texture of the tile and to fill the voids using small-sized grains to prevent the formation of bubbles that may cause cracks in the formation of the tile, and this is discussed in the results later on.

2.2 Objectives:

According to the problem statement, the objectives are as follows:

► Reducing the number of waste tires and trying to recycle them for the best use.

► Improving the texture of the tile using different sizes of rubber particles with a proportional amount of resin.

►Attempting to reduce the cost of the tile while maintaining its quality and appropriate mechanical properties, through the use of small percentages of resin, in order to encourage the start of a small project that helps the country's economy.

For the first trial, the first batch of Polyurethane resin was obtained from the headquarters of the German company SONAX in Egypt. Polyurethane resin is a prepolymer that does not require a catalyst to accelerate the process of polymerization and bonding of rubber particles. It can be treated in ambient conditions, which gives the cured specific gravity of 1.13 g/cm^3.

For the second and third trials, in order to try different manufacturers and see how the resin affects the consistency of the mixture, the second batch of Polyurethane resin was obtained from the headquarters of the American company DOW in Egypt. It can be treated in ambient conditions, which gives the cured specific gravity of 1.09 g/cm^3. Polyurethane resin manufacturers refer to it as a fine-texture solid that is excellent for use in various rubber molding applications.

The components were prepared of the mixtures at ambient temperature, emphasizing the use of small quantities of Polyurethane resin in order to reduce the cost as much as possible. The components were mixed in a mechanical mixer at a speed of 50 Rev/min (rpm) for 5 minutes to ensure that the rubber granules are saturated with Polyurethane. Then the mixture is spread on the molds at ambient temperature with an appropriate and regular distribution as shown in **Figures 2-a, b.**

The pressing process was carried out under controlled temperatures using a thermostat. The upper plate of the molds was set at a higher rate of temperatures by a difference of about 20 degrees Celsius (°C), in order to compensate for the percentage of heat loss transmitted from the upper surface to the mixture, while the applied pressure was 100 bar in a hydraulic press that shown in **Figure 3**, according to the composition of the different mixtures, this is explained later. **Figure 4** shows rubber sheet after drying out.

Figure 2-a: The Rubber-Resin tiles sheet immediately after pressing

Figure 2-b: The Rubber-Resin tiles sheet during removal from the plate

Figure 3: The Rubber-Resin tiles sheet during pressing

Figure 4: Compressed Rubber Resin Tiles Sheet After Dry Out

In all mechanical properties, GALDABINI-QUASAR 600 testing machine was used, it has self-calibration, zero adjusting, and automatic balancing. After removing the rubber-resin sheet from the hot mold, a tensile test was done according to ASTM D 412 [14], The produced sheets were cut using a dog-bone shaped die to cut out the required dumbbell samples. **Figure 5** shows some of the dumbbell samples during cutting.

Figure 5: Some of the dumbbell samples during cutting

A compression test was conducted according to ASTM 575 [15] which was done on some conditions such as contact load 1N, contact speed 5 mm/min, and test speed 12 mm/min.

The tests were conducted on rubber samples, and there were five factors affecting the texture of the rubber tile, that are: the proportions of sizes of rubber particles used, the percentage of resin, exposure of the resin to moisture, temperature, and pressing time.

All tests were conducted at the National Research Center in Egypt, documented with official papers, and stamped with the seal of the accredited center. GALDABINI-QUASAR 600 testing machine was used to carry out the tensile test at a test speed of 50 mm/min. Pictures were taken of all samples during steps of pressing and testing, and 5 samples were analyzed for each mixture. **Figure 6** shows some of the samples after cutting.

Figure 6: shows some of the samples after cutting

According to ASTM D 2240 [16], a durometer shore A was used to evaluate the hardness of rubber samples.

According to ASTM D 573 [17], ageing was carried out for three samples that were kept for 170 hours, which is in real-time 3 months at 70 degrees Celsius (°C) as an aging deterioration test in an Air Oven.

3. RESULTS AND DISCUSSION

All test specimens were conditioned at 23 degrees Celsius (°C), with a humidity of 50 percent (%), and the needed calibrations, as well as balancing of the all used machines were always done.

The pressing and testing of rubber samples were conducted for three separate attempts, in each attempt some changes were made in the ratios of the factors mentioned earlier, namely: the proportions of sizes of rubber particles used, percentage of resin, exposure of the resin to moisture, temperature, and pressing time.

In the first attempt, the main objective was to determine the appropriate conditions and ideal factors affecting the pressing process, by pressing at 200 degrees Celsius (°C) for 20 minutes. Also, the ratio of polyurethane resin to the percentage of rubber used was identified in various sizes of its granules, this is clarified in the results of the three sheets in **table 1**, where 2 sheets were compared with each other by fixing the percentage of resin, and between 2 sheets by fixing the percentages and sizes of rubber used.

The highest stress in the samples (S1, S2) are approximately equal in tensile strength (0.275 N/mm^2). And as a comparison between (S1, S3), the tensile strength in (S1 = 0.2759 N/mm^2) is greater than (S3 = 0.1658 N/mm^2) which proves that when grain size gets bigger, the tensile strength increases. All of the samples have an elastic behavior, and when they reach the yield strength, the samples will break. The sample (S1) has a maximum value of elongation (53.34% = 40.5 mm) because this sample has a greater percentage of greater size (mesh 10 = 2 mm) and Polyurethane resin. So the Polyurethane resin does not have an effective influence on the tensile strength but it affects the compression properties and hardness as shown in table 2. The sample (S2 = 486.8 Kpa) has higher compressive strength than (S1 = 246.8 Kpa) although (S2) contains less resin than (S1), this is due to exposure of these samples to air and moisture, and this explains the extent of the influence of external environmental factors on the properties of the resin.

Table 1: First trial (Mean values)

Formulation (Samples)	Tensile St. (N/mm²)	Elongation (%)	Compressive St. 25% (Kpa)	Hardness (Shore A)
S1 80% mesh 10 + 20% mesh 30 + 7% Polyurethane resin	0.2759	53.34	246.2	35
S2 80% mesh 10 + 20% mesh 30 + 3% Polyurethane resin	0.2752	43.595	486.8	45
S3 70% mesh 10 + 30% mesh 30 + 7% Polyurethane resin	0.1658	29.92	482.6	47

This trial was the start using the new formula of Polyurethane resin VORAMER* MR1101 by Egyptian supplier DOW company, there was a lockage of the information of the suitable pressing temperature, this trial revealed that this material does not need to be compressed at high temperatures, unlike the formula used in the previous experiment.

With experience, we concluded that the rubber sheet manufacturing process was carried out under rigorous temperature control during pressing, the upper and lower plates of the press-maintained temperatures of 150 °C and 130 °C respectively. Since the lower plate has the mold on it, it has to be set at a higher temperature to guarantee the same 130 °C on the top plate surface due to the heat loss by the mold thickness. Thus, the material at the end is between two surfaces at the same 130 °C.

Preliminary compatibility studies on bindings and rubbers are required. This was achieved by the tests that showed the following; there is no noticeable change or difference in the hardness and compression tests results, but worth noting are the results of the massive change in the tensile tests. These notes can be used as guide during the next trail which is shown in Table 2.

Table 2: Second trial (Mean values)

Formulation (Samples)	Tensile St. (N/mm²)	Elongation (%)	Compressive St. 25% (Kpa)	Hardness (Shore A)
S1 100% mesh 5 + 10% Polyurethane resin	0.2510	28.18	444	41
S2 70% mesh 10 + 30% mesh 30 + 10% Polyurethane resin 20 min pressing time 160 °C	0.341	52.47	256.3	47
S3 70% mesh 10+ 30% mesh 30 10% + Polyurethane resin Waiting 1hr	0.4331	93.74	257	44

In the third trial, the main goal was to reach satisfactory and competitive results by bringing samples from different companies and conducting tests on them. **Figure 6** shows 7 samples after the tensile test and the fracture. Results were very satisfactory as shown in **table 3**.

Figure 6: Fracture after tensile stress.

Table 3: Third trial (Mean values)

Formulation (Samples)	Tensile St. (N/mm²) Tensile after aging	Elongation (%) Elongation after aging	Compressive St. 25% (Kpa)	Hardness (Shore A)
S1 German company sample from market	0.9026 0.6851	87.14 64.303	598	63
S2 Hoppec company for rubber industries from market	0.8978 0.826	89.47 71.638	839	56
S3 70% mesh 10 + 30% mesh 30 + 7% Polyurethane resin 15 min pressing time	1.897 1.779	130.435 127.025	1245	67
S4 70% mesh 10 + 30% mesh 30 + 7% Polyurethane resin 10 min pressing time	1.917 1.845	125.4 114.575	1200	65
S5 70% mesh 10 + 30% mesh 30 + 10% Polyurethane resin 15 min pressing time	1.998 2.065	131.775 128.85	1174.5	62
S6 80% mesh 10 + 20% mesh 30 + 7% Polyurethane resin 10 min pressing time	2.01 1.607	126.263 118.3	1311.5	64
S7 60% mesh 10 + 20% mesh 5 + 20% mesh 30 + 7% polyurethane resin 10 min pressing time	1.605 1.552	118.475 108.965	1184.5	65

Chart 2 shows the results of the stress-strain curve before aging test. This show the highest value of tensile strength in sample (S6=2.01MPa) followed by (S5=1.998MPa), and (S4=1.917MPa), this indicates that these formations use the largest amount of rubber granules of large size, as the grain size increases, the tensile strength increases.

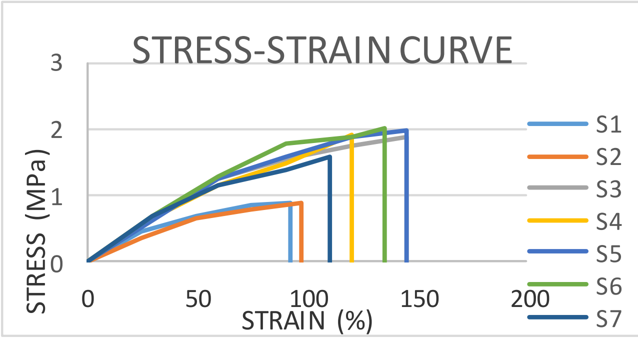

Chart 2: Stress-strain curve before aging test

The tests of accelerated aging were developed with modified testing conditions in such a way that affected by temperature and moisture over time. **Chart 3** shows the results of the stress-strain curve after aging test. These results show the difference between values before and after the aging test, we concluded that after using 3 months of real-time, the values of mechanical properties decreased as in (S6), which was 2.01 MPa, and became 1.607 MPa and this is the largest deviation of all samples. The test results indicate that there is no massive failure despite exposure to various environmental factors which support the idea of using multiple applications.

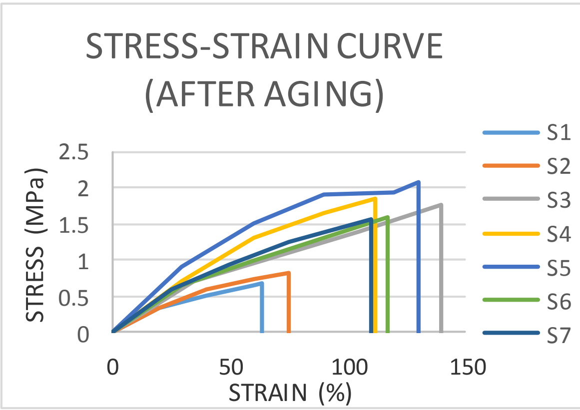

Chart 3: Stress-strain curve after aging test

In **Chart 4**, the maximum elongation is in (S5), which is 131.775 %, this means that the length of the sample has increased by more than twice its original length by 31.775 %. The composition of the sample is moderate and the proportion of small-sized granules used here is large compared to the rest of the mixtures, which is 30% it contains a percentage that is not the largest in terms of the size of the rubber granules. This could help to improve the connection between the rubber and the polyurethane resin due to its small size. resulting in a combination with improved elongation characteristics S5, S3, and S6 formulations are stiffer in general than others because they have bigger granulomere, and regardless of the resin concentration, the presence of larger tire rubber grains has a greater effect on the stiffness of the material than polyurethane resin.

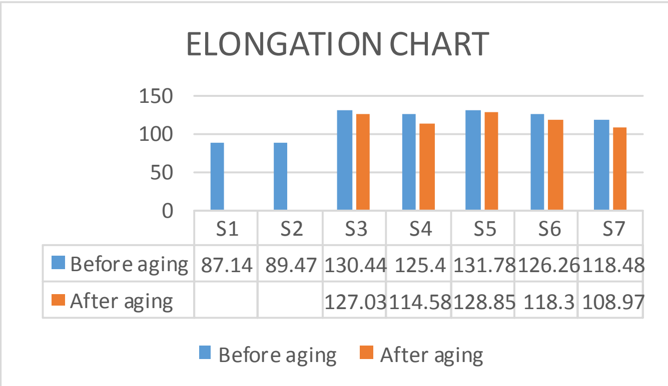

Chart 4: Elongation Results

Chart 5 shows the results of the compression curve. This show the highest value of compression in the sample (S6= 1311.5 Kpa), followed by (S3 = 1245 Kpa) and (S4 = 1200 Kpa). This indicates that these formations are affected by 2 factors to increase the values mentioned before, the percentage of polyurethane and then the amount of largest mesh sizes.

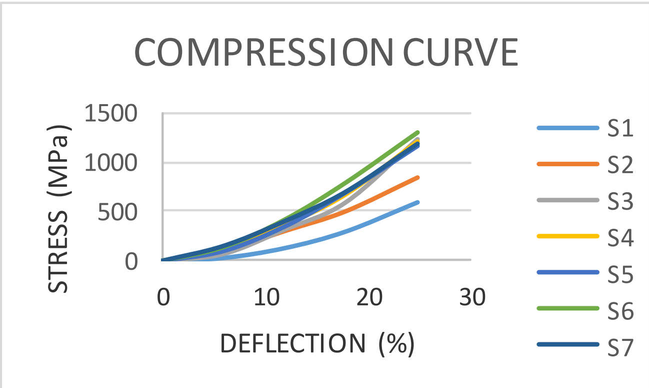

Chart 5: Compression Curve

A hardness test was conducted using a durometer Shore A. A durometer type A (F = 0.55 + 0.075 HA) is used, a hardened steel rod with a beveled cone at the tip serves as the durometer instrument. A gauge with a scale of 1 to 100 is activated by a spring-loaded steel rod. Under the beveled cone, the test sample is positioned straight. The instrument is then pressed against the material until the elastomer sample is leveled with the flat metal plate at the bottom. Higher numbers on the scale indicate more indentation resistance and thus harder materials. As a result, the higher the material hardness, the less the cone deforms the sample. Lower numbers on the durometer scale, on the other hand, imply less resistance to indentation and softer materials; hence, the more the cone deforms the sample, the lower the material's hardness [16]. The higher the durometer, the harder the material. As shown in **chart 6**, most of the values are between 60-70, this explains that the material is of medium hardness, as shown in **Figure 7**.

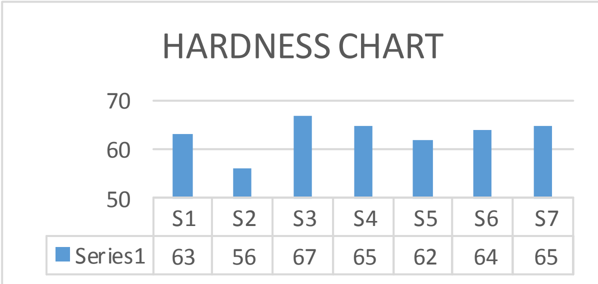

Chart 6: Hardness results

Figure 7: Hardness values range per application

4. Cost Analysis

This analysis was carried out according to the Egyptian prices in June 2022.

- **Fixed cost:**

Fixed cost = (1 x hydraulic press) + (1 x rubber mixer) + (2 x main conveyor). **(1)**

Total Fixed cost = (1 x 100,000) + (1x10,000) + (150,000) + (3x1,000) = (261,000 L.E).

- **Variable cost:**

A- Employee's cost:

(3 worker's x 3000) + (1 Maintenance worker x 3500) + (2 engineers x 5000) + (10000 renting cost) = 32500 L.E/month. **(2)**

B- Power consumption of the facility in one month:

Total power consumption/month:

Electricity cost: 1,824 KW/month x 1.55 LE.KW.hr. = (2,850 LE). **(3)**

C- Powder Material using for production line in one month:

Per month, 500 LE/day (meshes) x 6 days x 4 weeks = (12,000 LE/month). **(4)**

D- Polyurethane binder and Resin:

➢ **PU (Polyurethane)**
Per day will use (2.8 kg x 8 hr. x 60 min) / 30 min = 44.8 KG (9 gallons per day). **(5)**
9 gallons' x 6 days' x 4 weeks x 450 LE = (97,200 LE/month).

➢ **Resin**
Per day will use (0.4 kg x 8 hr. x 60 min) / 30 min = 6.4 KG (3.2 gallon per day). **(6)**
3.2 gallons' x 6 days x 4 weeks x 250 LE = (19,200 LE/month).

- **Total variable cost:**

V.C= 32,500 + 2,850 + 12,000 + 97,200 + 19,200 = 163,750 LE/month. **(7)**

- **Total cost:**

T. Cost = Total Fixed Cost + Total Variable Cost. **(8)**

T. Cost = 261,000 LE + 163,750 LE = 424,750 LE .

- **Variable Unit Cost per piece:**

Meshes Material: (3kg x 2600)/1000 = 7.8 LE.

7% PU which is 0.350 kg: (0.350 x 450)/5 = 31.5 LE.

50 grams of resin per mold cavity: (0.050 x 250)/2 = 6.25 LE.

Electricity used during production per piece: 9.5 Kw/hr. x 1.55 LE = 15 LE.

(Renting cost / total working hour): (10,000 / 8 hours' x 26 days) = 50 LE/hr.

Total cost per piece = 7.8+31.5+6.25+15+15+17+24+24+50 = 191 LE/hr. **(9)**

According to price of piece is 400 LE therefore, 400 LE – 191 LE = 209 LE.

- **Value Added Taxes**

Total revenue per unit after taxes = 209 x (100% - 22.5%) = 162 LE. **(10)**

- **Profit:**

Profit = Total revenue per month after taxes - Total V.C/Month. **(11)**

Profit = 162 LE/piece x 3,072 sheet - 424,750 LE/month.

Profit = 497,664 – 424,750 = 72,914 LE/Month.

- **Payback Period:**

Facility payback period = Fixed Cost/benefits = 261,000/72,914 = 3.5 months **(12)**

- **Break-Even Point:**

Breakeven point = Fixed cost / (revenue per unit – variable cost per unit). **(13)**

Breakeven point = 261,000 / (400 – {191+46}) = 1,601 quantity.

Chart 7 shows the unit sales breakeven analysis.

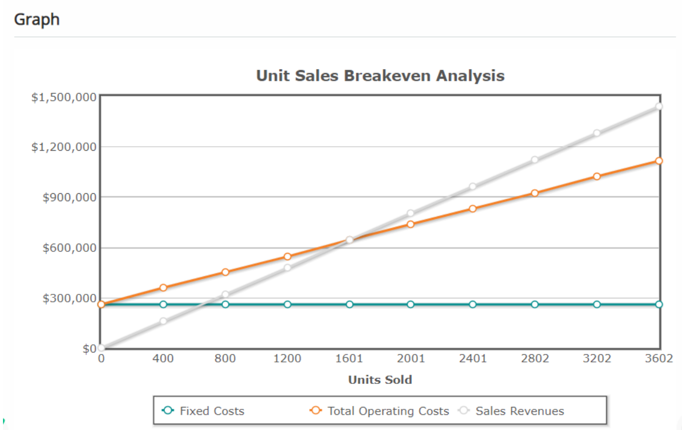

Chart 7: Unit sales breakeven analysis

5. CONCLUSION

To sum up, the results achieved the main target of this research which is the amount of rubber used is too large compared to the resin. That decreases the number of waste tires that led to solve the global environmental problem. Different particle size distributions, rubber contents, and tests were used by doing three trials to enhance the mechanical properties of the rubber tile were carried out. In the first and second trials, the main goal was to determine the optimum influencing factors for pressing in terms of temperature and time. In the third trial, results of the tensile strength were really good and this supports ability of the material to resist tearing due to tension. Compressive strength can also withstand loads tending to reduce size. Hardness values are enough to fare when it comes to indentation. Aging tests have a key role in determining the life-time under the influence of various environmental factors. All these good mechanical properties values help the product to be able to be used in different applications.

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