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Effect of Silica on the Mechanical Properties of Rubber Reclaim Composite

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Abstract: This study deals with preparation of rubber composite material, which is mainly used as sport floors, especially for kindergarten grounds. The selected material is reclaim rubber that is available at the state company for tire industry in Al-Najaf city - Iraq. The reclaimed rubber (R) (as a matrix) was mixed with different ratios of other rubber that is Styrene-Butadiene (SBR). It works as a bonding material.An additive which is cement kiln dust (CKD) was employed as a reinforcement phase. The ratios of the R to the SBR was as the following (100R), (95R+ 5SBR), (90R + 10SBR), (85R + 15SBR) and (80R + 20SBR). Different ratios of the CDK (10, 20, 30, 40, 50) pphr was added for each of the above mentioned batches. (80R + 20SBR + 40CDK) batch showed a promising behaviour and therefore was selected for furthers investigations. In order to improve its behaviour,SiO_2 was introduced as a second additive.The silica was added to the selected batch with ratios of (5, 10, 15, 20) pphr. The best results are of the batch contains 15 pphrsilica. They reveal that the resilience was 62.2% before adding the SiO_2, while it became52.2%after adding SiO_2. In addition, the hardness was 62.5 Shore A without SiO_2 and it has been62.3 ShoreAwith SiO_2. The UV influence and thermal aging will be discussed in the following pages.
Keywords : Reclaim , Silica, Reinforcement, Aging.

1. Introduction

The wastes of rubber have a harmful impact on the environment. Therefore, solving of this problem is an urgent matter by developing new applications for those wastes[1-12]. Use of rubber-based composite materials was recently increased in different aspects of industry. They occupy an extreme significance in research because of its unique characteristics such as its high elasticity and its ability to tolerate a series of stresses without permanent deformation. Mainly, they are used as dampers that absorbs the vibrations and the impact energies[4,5].

Damaged tires, which have been used for more than half of its operational life, are one of the types of solid waste. They are classified as one of the growing environmental issues in last few years. Many researches, which have been worked on damaged tires graveyard, stated that it is a source of many poisoned gases which negatively affect the life of living beings. Gases emit from treating damaged tires by uncontrolled incineration are CO, SO_X, NO_X, and volatile and non-volatile organic compounds as well as compounds absorbed by soil[3,4,13]. Consequently, these wastes should be treated in an economic and healthy manner; therefore, recycling tires are the perfect solution to get rid of this problem. Reclaim rubber is one product of those tiers that is produced after series of technical steps lead to a fresh rubber material, which would be ready for new applications, for instance, sport grounds.

Kindergartens yards in Iraq suffer from a lack of safety procedures. In order to prevent children from severe injuries, play grounds – that have a little resilience to absorb impact shocks, help children to get up and to continue playing – present the key element of children safety procedures. Such grounds must appear a resistance to weather conditions, especially UV which reduces the operational life of them.

The aim of this study is to design a rubber batch, which has the ability to exhibit desirable mechanical specifications with keeping a resilience to absorb impact energy.

2. Experimental Part

2.1 Materials

- Reclaim Rubber: it was brought from the state company for tire industry in Al-Najaf city - Iraq, which is an product of recycled rubber.
- Styrene-butadiene rubber (SBR): it was brought from the same above company.
- Silica**:** it is an oxide of silicon with the chemical formula SiO_2. It is used as a filler added to the rubber tires that contacts the grounds and conveyor belts[2].

2.2 Preparation of rubber composite

Reclaim rubber is used as a main material by 100% with using vulcanization materials including Zinc Oxide by 5g, Stearic Acid by 2g as activating materials, CBS material by 1.2g as an accelerating material, Sulfur by 1.8g as a vulcanized material, and drops of oil which are the basic components of the paste. Basic paste is prepared by the method of mixing the components of rubber paste by using the Italian presser " Comerio Ercole Busto Avsizo". Mixing and pasting process is performed by using this presser according to ASTM D15 , including (50$\pm$5)°C, and sequence of adding materials to presser and time period required for homogeneity for each material. Several improvements, proposed for basic paste, were performed and enhanced by SBR as a bonding material by (5,10,15,20)%, and CKD as reinforcement material by (0,10,20,30,40,50)pphr for each paste. Therefore, there are 6samples for each paste. According to results of mechanical tests, the paste (80Reclaim+20SBR+40CKD) was selected, then silica was added by (5,10,15,20) pphr. Impacts of exposing rubber paste samples (80Reclaim+20SBR+40CKD+15SiO_2) to UV were tested. It is the best percentage of Silica additive that meets the requirements of kindergarten grounds by using (NASWIETLACZ UV 2548) (42Watt) according to ASTM-D-1148-70 for different time periods, where the samples were exposed to four time periods (15,30,45,60) hours.

The tensile tests, four dumbbell shaped specimens were cut from the molded sheets with a thickness of about 2 mm and tensile tests were conducted according to ISO 37 using a universal tensile testing machine (model Instron 3366) at a crosshead speed of 500 mm/min. The tensile strength, elongation at break and tensile modulus (M100, M200 and M300) data were evaluated from stress-strain determinations and average values from four repeated tests for each vulcanization were recorded.

In the hardness test, the measurement was conducted using a Shore A type durometer in accordance to ISO 7619.The measurement of the hardness was made on three different points distributed over the specimen and average value was determined.

3. Results and Discussion

3.1Elastic properties

Figures (1),(2) and (3) show the effects of adding Silica (SiO_2) by ratios (5,10,15,20) pphr upon tensile property, elasticity module and elongation for the Supported rubber batch(80R + 20SBR + 40CDK) These figures show that there is a gradual decrease in tensile curve and values of elasticity module. Furthermore, it was noted that there is an increase in elongation values and an increase in weight percent of silica additive which remarkably appears at the addition ratio (15pphr SiO_2) , this occurred because adding silica leads to occurring lattice correlations between rubber chains and additives, and increasing the added silica rations causes an increase in the amount of lattice correlations which leads to transverse micro cracks inside the material which gives the material a flexible spongy nature to weaken tensile strength, decrease the values of elasticity module, and increase elongation values.

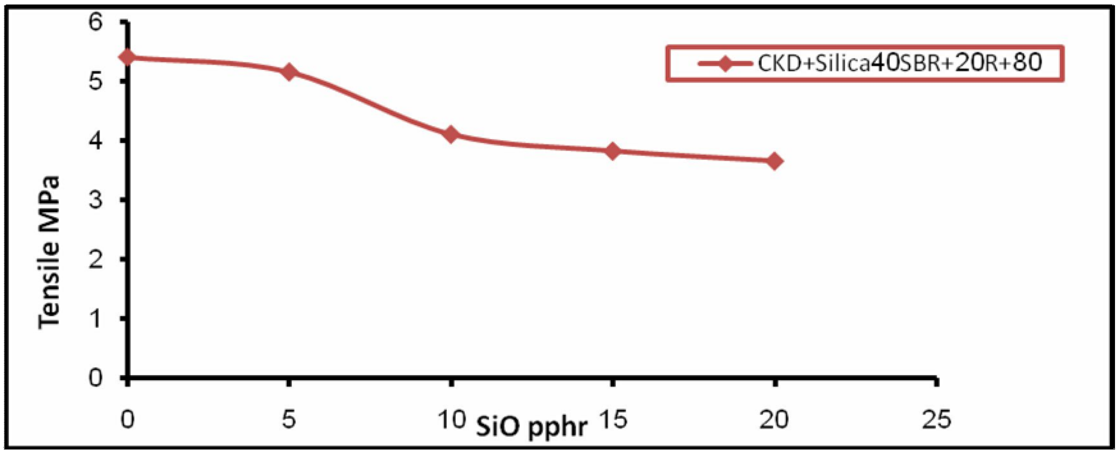

Fig. 1: Effect of SiO_2 ratio on the tensile strength

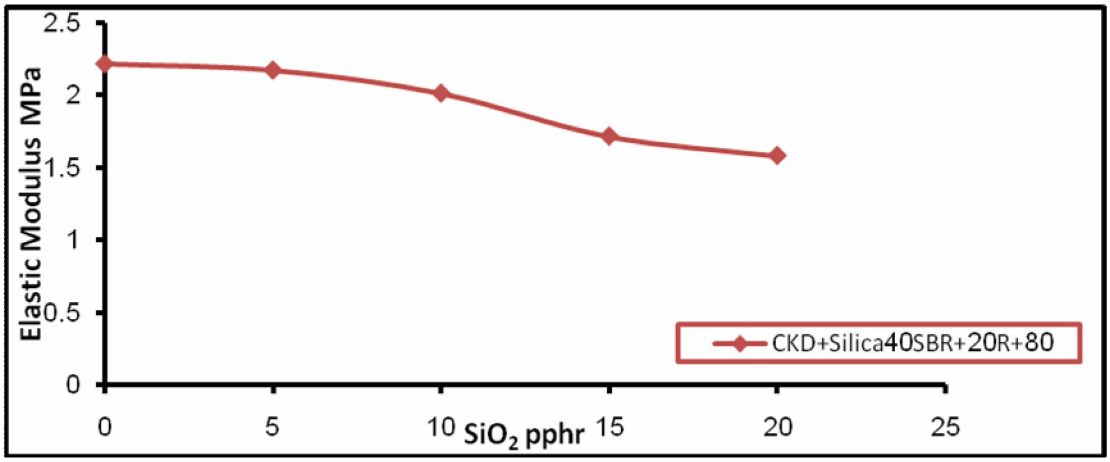

Fig. 2: Effect of SiO_2 ratio on the elastic modulus

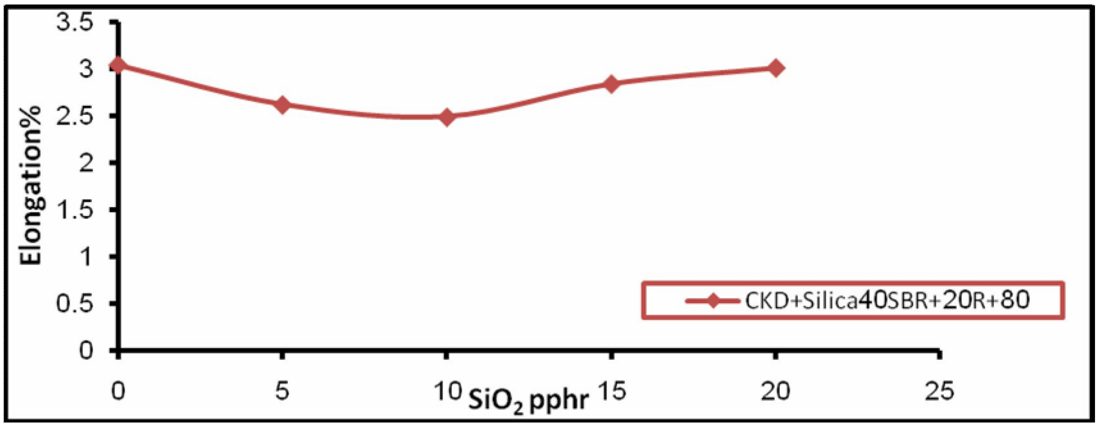

Fig. 3: Effect of SiO_2 ratio on the elongation.

3.2 Tear Resistance

Figure (4) shows the effect of adding Silica by (5,10,15,20) pphr on the property of tear residence for the supported rubber batch(80R + 20SBR + 40CDK). It is noted that the curve of tear resistance is rapidly increasing when increasing the ratios of silica additive SiO_2(10 pphr and 5 pphr), then slows down at 15 pphr and starts decreasing. This is occurred because adding silica leads to an increase in the amount of lattice correlations, and this results in transverse micro cracks inside the product causing an increase in tear resistance of the material and roughness in the material surface to increase wear.

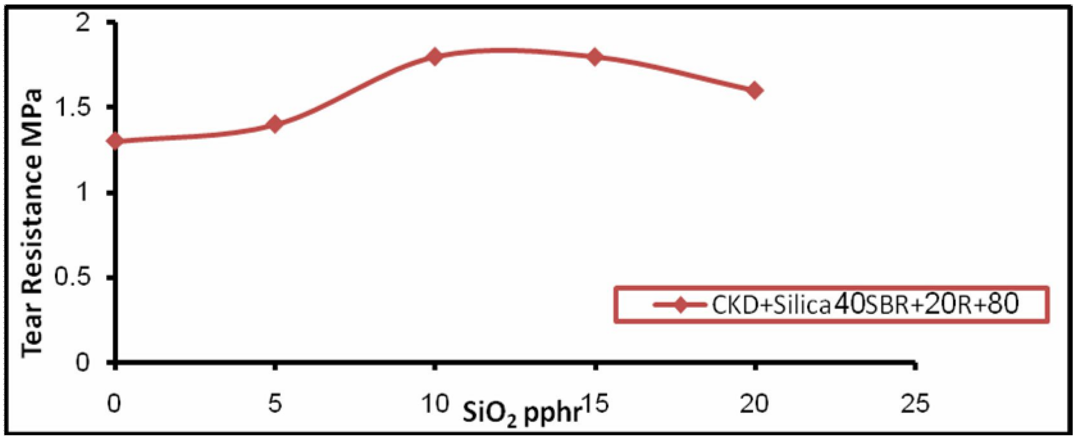

Fig. 4: Illustrates the effect of SiO_2 ratio on the tear resistance

3.3 Specific Gravity

Figure (5) shows the effects of adding silica by ratios (5,10,15,20) pphr on the specific weight of the supported rubber batch(80R + 20SBR + 40CDK). In general, we can observe a gradual increase in specific weight by adding the ratio of silica additive. This occurred because silica is working as a visceral material filling spaces in rubber paste, causing an increase in product density and an increase in specific weight and this is consistent with researcher's findings when studying the effects of adding silica on NBR[14].

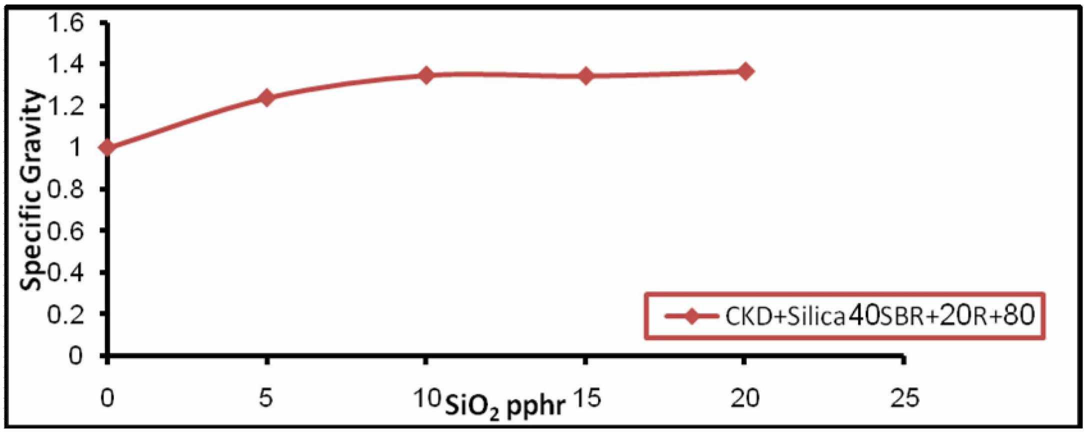

Fig. 5: Shows the effect of SiO_2 ratio on the specific gravity

3.4 Resilience

When comparing the resilience values obtained before adding silica to selected rubber paste (80R + 20SBR + 40CDK) with corresponding values after addition as in figure (6), we find a significant decrease in resilience values which increases when increasing the added silica ratio all the way to 15 pphr. Increasing the silica ratio causes micro cracks inside the material, making it a sponge rubber with the ability to absorb impact force and dissipate it in form of heat inside the material, i.e., it is working to damp the impact force, and thus the resilience decreases. Therefore, this product by 15pphr as an additive ratio can be used in the industry of kindergarten playgrounds or sports grounds. However, the increase in resilience values when increasing silica ratios from 15 pphr to 20 pphr, can be construed on the basis of silica aggregates inside the material.

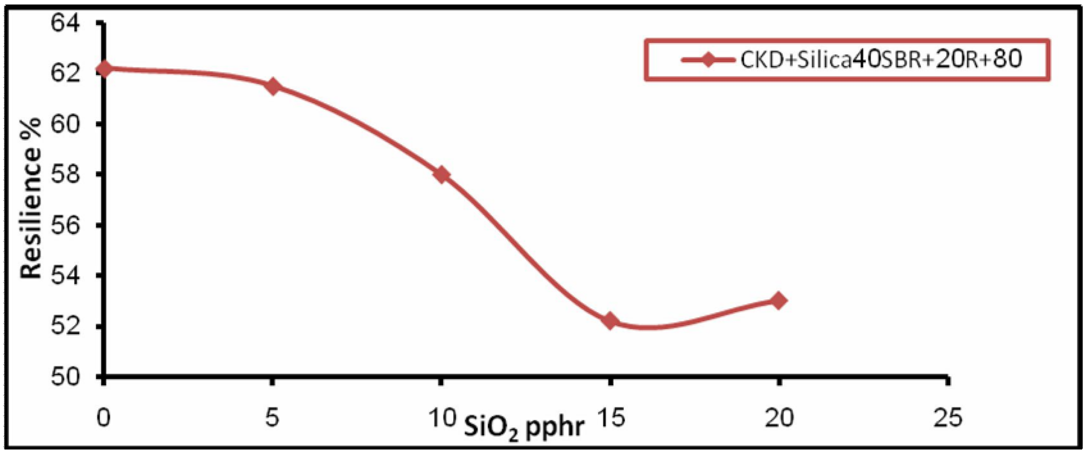

Fig. 6: Shows the effect of SiO_2 ratio on the resilience.

3.5Hardness

Figure (7) shows the effect of adding silica SiO2 by ratios (5,10,15,20)pphr upon the property of hardness for the selected rubber paste (80R + 20SBR + 40CDK). When comparing value of surface hardness number of selected rubber paste sample before adding silica with corresponding values after addition, we find an increase in values of hardness number at addition ratios (5 pphr and 10pphr) because of lattice correlations between rubber chains and additives. It is followed by a significant decrease in hardness number values with an increase in silica additive ratio all the way to 20 pphr. This is occurred because of the significant increase in the amount of lattice correlations inside the product with an increase in the amount of additive which is leading to generate longitudinal and transverse micro cracks in form of Microspores to give the material an elastic spongy nature in order to decrease hardness of material.

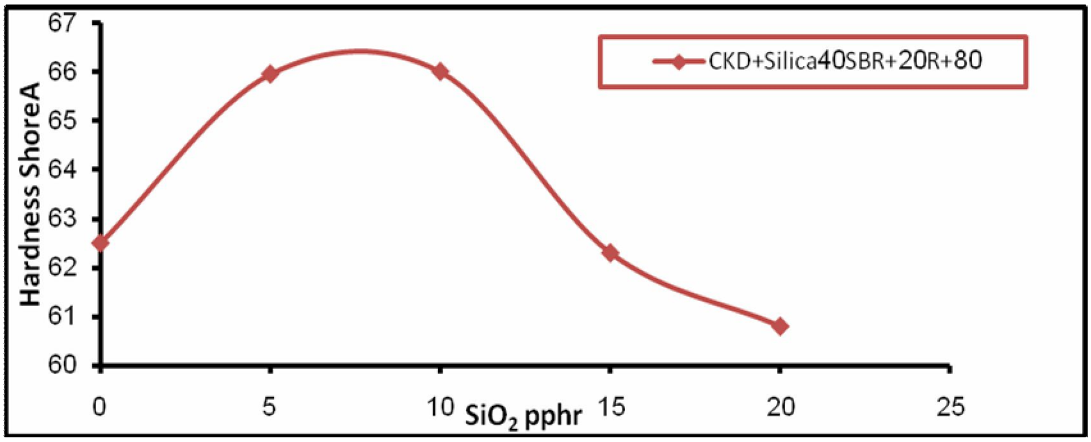

Fig. 7: Reveals the effect of SiO_2 ratio on the hardness

3.6 Compression

Figure (8) shows the effects of silica addition by (5,10,15,20) pphr on the property of compression resistance of selected rubber paste (80R + 20SBR + 40CDK). When comparing the compression resistance value of the product after adding silica with corresponding values before addition, we find an increase in compression resistance values for all addition ratios. It is occurred because the increase in the amount of additive causes creating new lattice correlations inside the product, and these correlations constrain the movement of rubber chains and thereby increasing compression resistance.

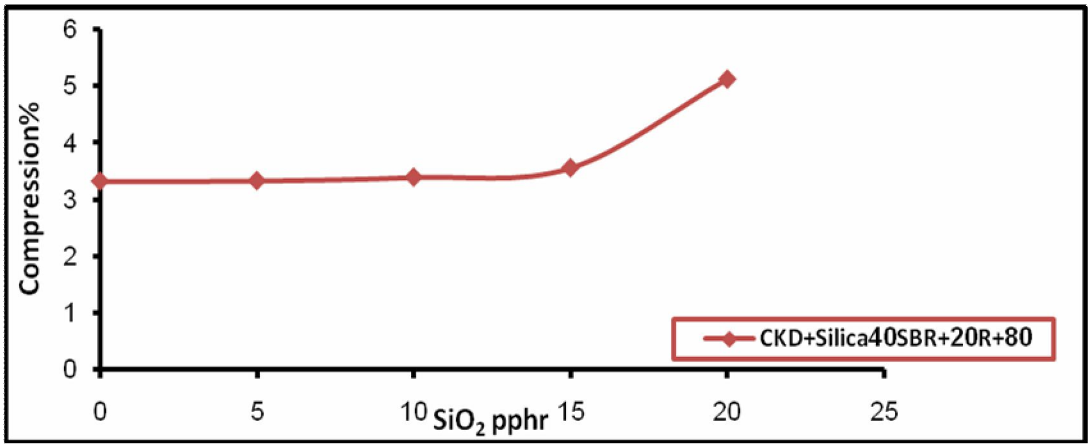

Fig. 8: Shows the effect of SiO_2 ratio on the compression

4. Results of exposing to UV Rays

Testing the effect of exposing to UV rays was conducted on properties of tensile, hardness, resilience, and specific weight of rubber paste samples (80R+20SBR+4040CKD+15Silica). The bellow are the alignment charts for some mechanical tests.

4.1The effect of exposing to UV rays on property of tensile strength

Figure (9) shows the effect of exposing to UV rays on property of tensile strength of selected rubber paste sample (80R+20SBR+40ash+15Silica). It is noted that there is a slight increase in tensile strength value in the first period of exposing to UV rays, i.e. (15 hr.) which was 3.85 compared to corresponding value when not exposing to UV rays which was 3.821, i.e. with an increase in range amounting at 0.75% due to an increase in the amount of lattice correlations between rubber chains and additives and thereby increasing tensile strength. By prolonging the period of exposing to UV to 60 hr., the ray will crack bonds near to surface and create free radicals in rubber chains working on forming new lattice correlations leading to generate longitudinal and transverse micro cracks inside the material which appear in form of micropores, giving the material an elastic spongy nature, and thereby occurring a drop in tensile strength by 3.3. This means that there is a decrease in tensile strength value by 15.7% comparing to the value measured before exposing to UV rays, and this is constituent with previous research[15].

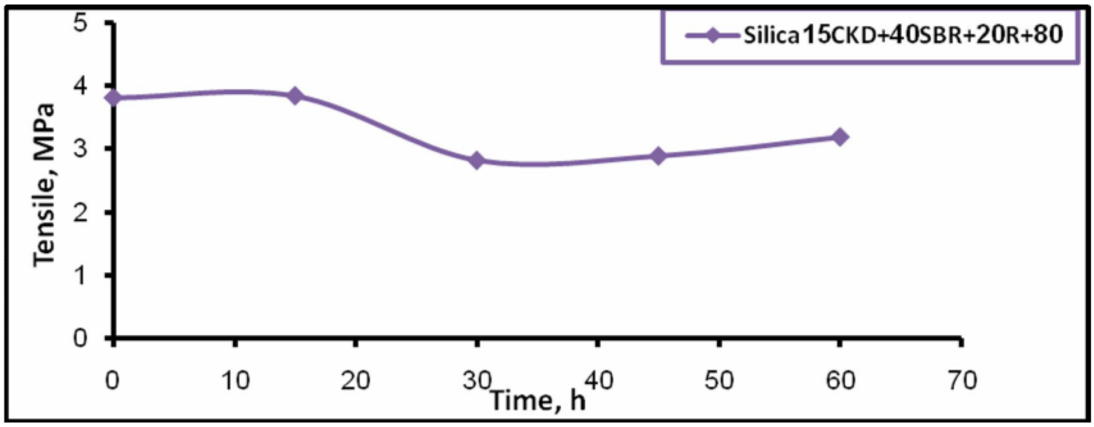

Fig. 9: Shows the effect of explosion of UV on the tensile

4.2Effect of exposing to UV rays on property of hardness

Figure (10) shows the effect of exposing to UV rays on property of hardness of selected rubber paste sample (80R+20SBR+40ash+15Silica). It is noted that there is an increase in hardness number value at the beginning of exposing to UV rays, i.e. the period to (30hr.) which was 66 compared to corresponding value when not exposing to UV rays which was 62.3 , i.e. with an increase amounting at 5.94% due to an increase in the amount of lattice correlations and thereby increasing hardness. By prolonging the period of exposing to UV to 60 hr., the rays will crack bonds near to surface and create free radicals in rubber chains leading to form new lattice correlations working on generating transverse micro cracks inside the material which appear in form of micropores, giving the material an elastic spongy nature, and thereby occurring a slight drop in hardness by 60.8. This means that there is a decrease in hardness number values by 2.407% comparing to the value measured before exposing to UV rays. This result indicates that rubber product has good specifications that qualifies it to be used in the field of industrial application represented in casting kindergarten yards.

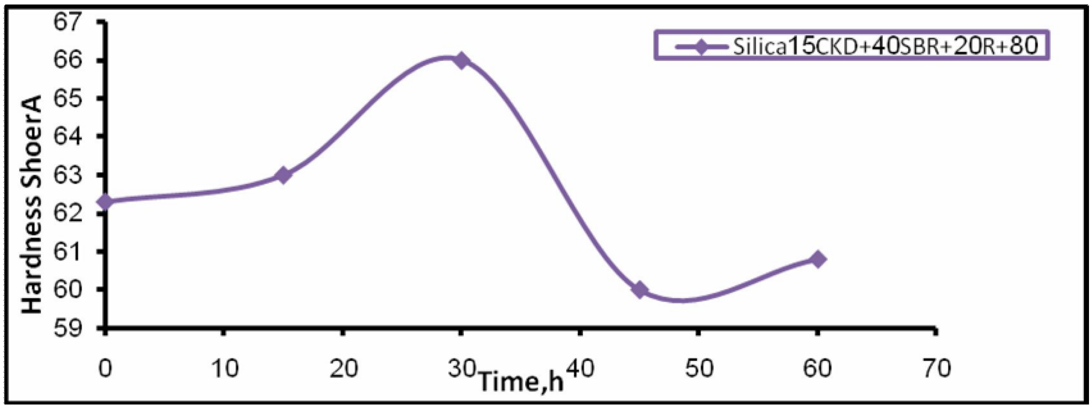

Fig. 10: reveals the effect of SiO_2 ratio on the hardness

4.3 Effect of exposing to UV rays on resilience property

Figure (11) shows the effect of exposing to UV rays on property of resilience of selected rubber paste sample (80R+20SBR+40ash+15Silica). The results of property of resilience indicate that there is an increase in resilience value at the beginning of exposing to UV rays, i.e. the period of (15 hr.) by 12.56% because of the increase in lattice correlations and thereby increasing resilience. By prolonging the period of exposing to UV to 60 hr., the rays will crack bonds near to surface and create free radicals in rubber chains to form new lattice correlations leading to generate longitudinal and transverse micro cracks inside the material which appear in form of micro pores, giving the material an elastic spongy nature, and thereby occurring a drop in resilience value by 0.766% comparing to the value measured before exposing to UV rays. This result indicates that rubber product is not affected by rays, and therefore, the material is capable to absorb impact energy and dissipate it in form of heat inside rubber chains and this leads to decrease the impact force of fall which is required in application.

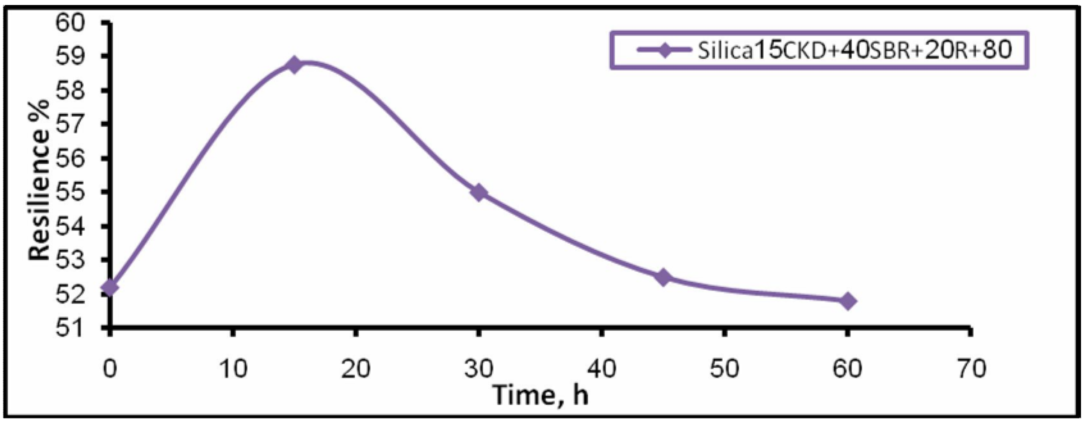

Fig. 11: Reveals the effect of SiO_2 ratio on resilience.

4.4 Effect of exposing to UV rays on specific Gravity property

Figure (12) shows the effect of exposing to UV rays on property of specific weight of selected rubber paste sample (80R+20SBR+40CKD+15Silica). It is noted that there is an increase in specific weight values at the beginning of exposing to UV rays to reach to (30 hr.) comparing to corresponding values if it is not exposing to UV rays, and it is due to the above cited reasons. The decrease in specific gravity by prolonging the period of exposing to UV to reach to (60 hr.), is due to forming longitudinal and transverse micro cracks resulted from increasing the lattice correlations inside the material.

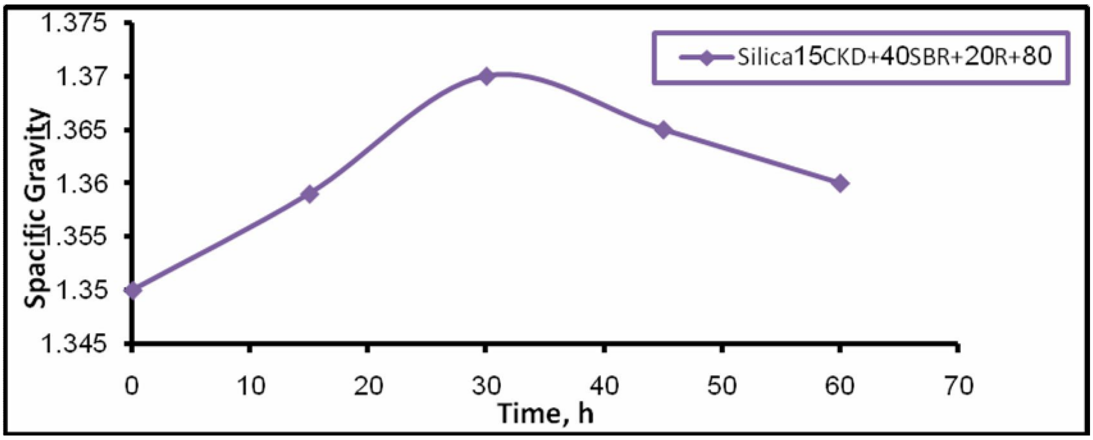

Fig. 12: Shows the effect of SiO_2 ratio on the specific gravity.

5 Results of aging the selected batch

The rubber paste consisting of (80R+20SBR+40CKD+15SiO2) was selected because it has mechanical specifications suitable for producing kindergarten grounds. After that, thermal aging test of resilience and hardness properties was conducted to identify the effects of sunlight . Samples of resilience and hardness were put in a kiln for 72 hr. at 70°C. Results of aging gave a hardness number value amounting at (64.25 Shore A) and (55.7%) resilience. When comparing these results with corresponding values before thermal aging, we find that the slight increase in the values of hardness and resilience properties is due to an increase in the amount of lattice correlations inside the material by the impact of heat on product sample. From the above, we conclude that the effect of exposing to UV rays and thermal aging on mechanical properties of the product was within the acceptable limits to be used in industrial application represented in cladding kindergartens yards.

5.1 Comparing results of the research with American and German standards

When comparing results of rubber product's mechanical properties prepared according to American standards for products of the American Beam Clay® used in cladding kindergartens yards, it was noted that there is a good consistency in tensile and hardness values as shown in table (1), where tensile property is largely improved comparing to results of American business model. Number of hardness was highly consistent with American business model and it clearly appears through reviewing the results listed in the above cited table.

Results of acceleration by thermal aging for (72hour) at 70°C showed a hardness number value of (64.24 Shore A) for rubber product prepared by us. i.e. it is higher than the hardness number value before aging and which was (62.3 Shore A). The comparison between these results and results of American specification for business product stated in table (1) indicates that our results are within product's specifications before and after aging, and this refers that the product is not affected by head, and thereby accepted to be used in industrial application representing in casting kindergartens yards.

when comparing results of the prepared product's resilience property after aging by UV rays with our results of German specifications for sports grounds shown in table (1) and since kindergartens yards are required to have low resilience property to damp fall impact comparing with high resilience for sports yards, we find that our results are within require specifications.

Table (1) a comparison between results of business model test and the research results.

<table>
<tr><th>Link</th><th>ASTM</th><th>German Standard</th><th colspan="2">Standard of Beam Clay®</th><th colspan="2">Our results</th><th>Properties</th></tr>
<tr><td>[6]</td><td>D412</td><td>-</td><td colspan="2">Minimum 0.8618</td><td colspan="2">3.821 MPa</td><td>Tensile</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">D2240</td><td rowspan="2">-</td><td>After aging</td><td>Before aging</td><td>After aging</td><td>Before aging</td><td rowspan="2">Hardness</td></tr>
<tr><td>100% (± 5%)</td><td>65 ± 5 ShoreA</td><td>64.25ShoreA</td><td>62.3ShoreA</td></tr>
<tr><td>[7]</td><td>DIN-18035</td><td>After aging UV ≤ 90%</td><td colspan="2">-</td><td colspan="2">After agingUV 51.8%</td><td>Resilience</td></tr>
</table>

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