Contents lists available at http://qu.edu.iq

Al-Qadisiyah Journal for Engineering Sciences

Journal homepage: https://qjes.qu.edu.iq

Utilizing sulfur and zinc oxide to improve impact in hard rubber recipe designs

Muthana H. Abdul Hussein [1], Nabel Kadum Abd-Ali [1] and Abdussalam Ali Ahmed [2]

[1] *Department of Mechanical Engineering, College of Engineering, University of Al-Qadisiyah, Iraq*
[2] *Department of Mechanical and Industrial Engineering, Faculty of Engineering, Bani Waleed University, Libya*

ARTICLEINFO

Article history:
Received 24 February 2024
Received in revised form 29 June 2024
Accepted 02 August 2024

Keywords:
Sulfur
Natural rubber
Carbon black
Hard recipe
Hardness
Zinc oxide
Armor plates

ABSTRACT

The current work represents a practical study with the aim of getting the best design for hard rubber recipes by controlling materials that increase this property. Rubber recipes were prepared consisting of several materials, such as natural rubber, zinc oxide, and stearic acid, in addition to the accelerator and vulcanizing agent sulfur, which was added in multiple proportions 10, 20, 30 parts per hundred rubbers (PPHR). Also, recipes were prepared for the same previous ingredients with an increased percentage of Zinc oxide to 150 PPHR to demonstrate the effect of this material on the hardness property. Some laboratory tests were conducted to investigate the mechanical behavior of these recipes, such as hardness, tension, and Rebound (resilience) tests. The recipe with sulfur 30 pphr gave an acceptable indication in hardness and tensile test with values 98 IRHD and 35 MPa respectively. The same recipe in the rebound test was not the best but was an acceptable result, while the recipe with sulfur 10 pphr was the best in resilience test results (25%). Other rubber recipes with zinc oxide at 150 PPHR gave acceptable results especially in recipes with sulfur at 30 PPHR. Two forms of the composite plate covered with a hard rubber recipe may result in an external bonding process of individual plates and a vulcanized plate with a hard rubber recipe in a thermal press. The final hard rubber recipes may be used in other applications as an alternative material to withstand various stresses with specific properties.

1. Introduction

Composite materials are characterized by unique properties that make them a basic material for manufacturing engineering parts for various applications under various loads, such as using these materials in the manufacture of aircraft structures, vehicles, ships, etc. [1-8]. Rubber is considered one of the main components of rubber-based composite materials in the manufacture of many parts in vehicles and aircraft, including tires that are exposed to multiple stresses during movement and contact with the road [9-10].

The unique properties of rubber have made it an important material in the manufacture of many engineering parts, as it is used in agricultural, industrial, sanitary engineering applications, etc. [11-12]. Some previous studies have dealt with the factors affecting the manufacture of some rubber parts that are exposed to specific stresses under the influence of working conditions, such as heat, humidity, etc., where experimental recipes were made of rubber reinforced with carbon black (CB) and silica as a filler material for the manufacture of the rubber valve in the packing line of a cement factory, and the working conditions for this were determined.

* *Corresponding author.*
E-mail address: nabel.abdali@qu.edu.iq (Nabel Abd-Ali)

https://doi.org/10.30772/qjes.2024.147161.1139

Nomenclature:	
NR – Natural Rubber	MBTS - The thiazole class of accelerators (Benzothiazyl Disulfide)
KF - Kevlar Fiber	TMTD - Tetramethyl thiuram Disulfide
CF - Carbon Fiber	IRHD - International Rubber Hardness Degrees
GF - Glassfiber	PPHR - Parts per Hundred Rubber
ZnO – Zinc Oxide	S – Sulfur

The rubber part, which is represented by 180 degrees Celsius and a pressure of 10 bar, and the best recipes to produce this valve and increase its operational life under conditions of alternating stress [13-14]. Other types of natural rubber and synthetic rubber were also used in different proportions to improve the screen dampers used in cement factories and to find the best recipe for producing these engineering parts [15]. One of the important uses of rubber recently is protection armor, as many rubber mats can be used to create walls with a high ability to repel projectiles and dampen their speed by taking advantage of the distinctive properties of rubber materials and their ability to absorb impact energy. Armor requires specific high specifications in addition to lightweight [16-17], therefore, the use of ceramic armor instead of metal armor at one stage [18-19]. The improved resistance and ease of manufacturing along with the light weight of armor composed of multi-layer composite materials make it a suitable alternative for producing these parts with advanced designs and better response to application conditions [20-21]. Several studies discussed matrices and reinforcement fibers of armor such as epoxy, polyurethane, and polyester resin, as Kevlar fiber KF, carbon fiber CF, and glass fiber GF in addition to natural fibers to investigate the factors that affect the ballistic impact of armor materials [22-25]. Boundary conditions such as velocity of impact were discussed previously [26], in addition to layer arrangements or sequence and fiber orientation it has been discussed in depth in much previous research in addition to factors that affect on mechanical behavior of these components such as dimensions and geometry [27]. Waste materials extracted from the tire recycling process were used as filler and reinforcement materials in rubber recipes to improve the performance characteristics of these recipes [28]. Another study discussed fracture and fatigue failure to investigate the determination of dynamic fracture initiation toughness using a special crack form [29] .

The current work focused on designing rubber recipes using natural rubber as a basis, whereby increasing the vulcanizing agent (Sulfur) was tried with three increasing loads, and then checking those same recipes with increasing the zinc oxide loading percentage. During this work, rubber sheets are made that will cover or surround the composite material plates that were manufactured in the previous part. The covering or enclosing process will be carried out in two ways: the first is the process of gluing the separate sheets using a bonding material, and the second is the process of vulcanizing a rubber cover surrounding the plates of pre-manufactured composite materials, which is done through a thermal press.

2. Experimental work

2.1 Preparation of rubber recipes

This stage represents an important stage through which the basic rubber compound type and proportions were selected through the use of two types of hard rubber compound, the first type using carbon black as a filler and the second type using zinc oxide as a filler material. By choosing the weight ratios shown in Table 1. where the weight of the rubber used as the base for the rubber compound in Parts per Hundred Rubber (PPHR) is based on the standard recipes of the experimental part. The primary material that gives the hardness is a filler material but to obtain high hardness the addition of high sulfur ratios is the main responsibility for the hardness. Hard rubber recipes are produced by changing the ratio of sulfur material to obtain a high hardness of the rubber compound. In this work, mix six types of rubber compounds by changing the proportion of sulfur material to obtain hard rubber recipes and perform some mechanical and physical tests on these recipes that have been prepared for the purpose of differentiating between them to reach the best description suitable for the engineering application required. In Table 2, the same recipes with a loading ratio of zinc oxide 150 pphr were conducted to investigate the effect of this addition on the mechanical behavior of these recipes.

Table 1. The different weight percent of Sulfur

Materials	PPHR		
	A1	A2	A3
NR	100	100	100
ZnO	004	004	004
Stearic Acid	002	002	002
CB	075	075	075
Dutrix Oil	010	010	010
S	010	020	030
MBS	002	002	002

Table 2. Different weight percent of Sulfur with zinc oxide impact.

Materials	PPHR		
	B1	B2	B3
NR	100	100	100
Zinc Oxide	150	150	150
Stearic Acid	2	2	2
Sulfur	10	20	30
TMTD	3	3	3

The process of mixing rubber compounds was carried out in accordance with the international standard ASTM D3182 which represents the specification. The mixing of compound materials by using the laboratory mill is shown in Fig. 1. Where The ASTM D3182 specification shows the process and time of materials mixing with the clarification of environmental conditions of humidity also the required temperature of the mixing process. After compound mixing is completed, it is left for a certain period of time in accordance with the standard ASTM D3182 to ensure the regular distribution of chemicals in the compound as well as the thermal stability of the compound before the start of other activities on it.

2.2 Vulcanization Process of Hard Rubber Recipes

A metal mold with special dimensions is configured as shown in Fig. 2, to produce covering hard composite by Hard rubber layers. Prepare a layer of hard rubber compound and put in the mold, then put the hard composite results from previous work as a center layer as shown in Fig. 3. That include three layers for each (Glass fiber/Kevlar fiber/Carbon fiber) respectively, then put a second layer of chosen hard rubber compound to be coated the Hard composite from both sides, then vulcanizing by electrical thermal press at a constant temperature. The vulcanization process was under 140 Cº for 35 minutes. After that remove the product from the mold and cooled at room temperature.

Figure 1. Two roll mills.

Figure 2. Hard composite mold, *(20 X 20) cm*

Figure 3. Composite plate from the previous stage *(20 X 20) cm*

3. Results and discussion

3.1 Hardness test

The first test was the examination of the hardness of the compound by vulcanized testing specimen by metal molds with special dimensions as in Fig. 4. The compound sample is placed inside the molds then placed in the electrical curing press which has a controlling temperature system as in Fig. 5. By a certain temperature and time, these testing specimens (discs) are obtained as in Fig. 6., then left to cool for a certain period of time and then the hardness of the models is checked with a device called Wallace Tester as in Fig. 7. and all this process is done according to the standard ASTM D2240. The results were as in Fig. 8. for the hardness property of the compound, noting that the result represents the average of three specimens of each one.

3.2 Tensile Test

One of the important physical properties that gives an important indication of the application is the tensile strength of the rubber compound. This examination is done through the vulcanization of rubber compound at a certain temperature and time through a special metal mold to give a vulcanized rubber sheet with fixed dimensions in terms of length, width, and thickness, range of thickness about (2 mm) as in Fig. 9. and Fig. 10., this process is done by the electric curing press. After leaving the testing specimen for a certain period of time to cool the testing sheet is cut to make the testing specimen which is called a Dumbbell by a special cutter and shown in Fig. 11. and Fig. 12. The Tensile strength specimen test using Tensometer testing machine and this process is done according to standard of ASTM 412.

Figure 4. Electric thermal press.

Figure 5. Hardness specimen mold.

Figure 6. Hardness Wallace Tester.

Figure 7. The hardness test specimen (d:12, h:24) mm.

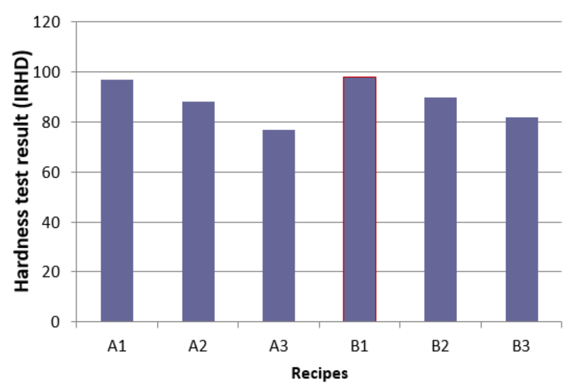

Figure 8. Hardness test results

Fig. 13. represents the results of the tensile strength properties of the compound, noting that the result represents an average of five specimens for each one.

3.3 Resilience test

The Rebound of the compound is checked by the Wallace rebound testing machine as in Fig. 14., by using a vulcanized specimen disc by certain specifications of temperature and time required for vulcanization as in Fig. 5. The testing method is in accordance with the standard ASTM 1054 where the rebound resilience % is measured according to the Eq.1.

$$\text{Rebound resilience \%} = \frac{(1-\cos A)}{(1-\text{c0s}B)} \text{ x } 100 \qquad (1)$$

Where, A, the initial angle (start angle) of the inspection arm and B, the return angle of the inspection arm after it has been hits the rubber specimen. Fig. 15. represents the results obtained for this testing; it is shown that the compound with the symbol A3 is the best in terms of the rebound test. The recipe (A3) is the best in terms of hardness (98 IRHD) and tensile strength (35 MPa) and gives acceptable results in the test of rebound (12%), also is compatible with the required application so can be used as a hard layer to shield hard composite plate that used for protecting cars or the walls of shooting halls. The final product illustration consisting of overlaid material layers enclosed or covered with hard rubber that was selected as the best rubber recipe for shielding and protection shield in vehicles and shooting hall with two approaches. External bonding process for individual plates as shown on Fig. 16, with vulcanized it with rubber recipe as shown in Fig. 17.

Figure 9. Tensile strength testing machine

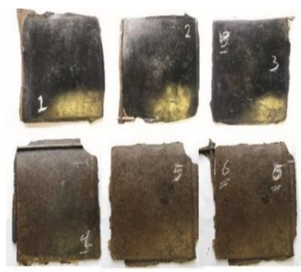

Figure 10. Testing sheets

Figure 11. Dumbbell shape cutter

Figure 12. Dumbbell shape specimen. 2 mm thickness and 165 mm effective length.

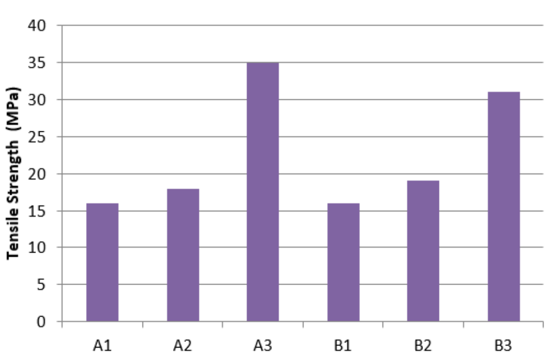

Figure 13. Tensile test results.

Figure 14. Wallace rebound device

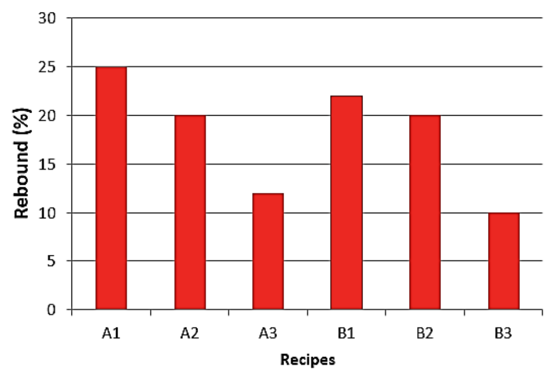

Figure 15. Rebound test results.

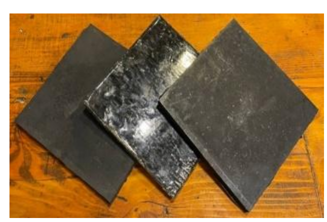

Figure 16. Individual plates.

Figure 17. Vulcanized plates with rubber recipe

4. Conclusions

The current study concluded with many important results that can be considered the basis for similar work with the aim of studying the properties of these materials and predicting their behavior during loading for use in important engineering applications.

1. The recipe (A3) (with sulfur 30 pphr) gives acceptable in hardness and tensile test with value (98 IRHD) and (35 MPa) respectively.
2. The value of recipe A3 in rebound test not the best but was acceptable in percent application for shooting galleries and vehicles armor plates.
3. Recipe A1 (with sulfur 10 pphr) was the best in Rebound test results (25%) the same value of carbon black (N375).
4. Other rubber recipes in group B give acceptable results specially in B3 recipe.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

Funding source

This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] Cai, J., Qiu, L., Yuan, S., Shi, L., Liu, P., & Liang, D., 2012 . Structural health monitoring for Composite Materials. In Composites and their applications. Intech Open. chapter 3

[2] O. Khayal, "Manufacturing and processing of composite materials," Manuf. Process. Class. Compos. Mater, no. July 2019 doi: 10.13140/RG.2.2.30822.57928.

[3] F. Tornabene, N. Fantuzzi, M. Bacciocchi, and E. Viola, "Accurate inter-laminar recovery for plates and doubly-curved shells with variable radii of curvature using layer-wise theories," Compos. Struct., vol. 124, pp. 368–393, 2015. doi: 10.1016/j.compstruct.2014.12.062.

[4] A. E.- Helloty, "Dynamic Response Of Laminated Composite Shells Subjected To Impulsive Loads," IOSR J. Mech. Civ. Eng., vol. 14, no. 03, pp. 108–123, 2017. doi: 10.9790/1684-140301108123.

[5] S. Edition, *Mechanics of*, no. January 2001. 1999.

[6] L. Mullen, "Chapter 10: Composite Materials," *Chicago Rev.*, vol. 46, no. 2, p. 67, 2000.

[7] S. Carolina, *Zy Zyxwvu Zyxwv*, vol. 219, no. September 1990. 1994

[8] Leister, G., 2018. Passenger Car Tires and Wheels: Development-Manufacturing-Application. Springer

[9] J. S. Chohan, K. S. Boparai, R. Singh, and M. S. J. Hashmi, "Manufacturing techniques and applications of polymer matrix composites: a brief review," *Adv. Mater. Process. Technol.*, vol. 8, no. 1, pp. 884–894, 2022. doi: 10.1080/2374068X.2020.1835012

[10] Kim, J. K., Saha, P., Thomas, S., Haponiuk, J. T., & Aswathi, M. K. (Eds.)., 2018. Rubber recycling: challenges and developments. Royal Society of Chemistry

[11] T. Lei, Y. W. Zhang, D. L. Kuang, and Y. R. Yang, "Preparation and properties of rubber blends for high-damping-isolation bearings," *Polymers (Basel).*, vol. 11, no. 8, 2019. doi: 10.3390/polym11081374.

[12] Abd-Ali, N. K., Farhan, M. M., & Hassan, N. Y., 2021. Improvement of Mechanical Properties of the Rubbery Part in Cement Packing System using New Rubber Materials. Journal of Engineering Science and Technology, 16(2), pp.1601-1613.

[13] Fahem, Ali Fahad,Vijendra Gupta, Addis Kidane, Michael A. Sutton, "Determination of Mixed-Mode (I/III) Fracture of Polycarbonate (PC), " SEM 2020 Annual Conference on Experimental and Applied Mechanics, March 2021, Virtual Annual Meeting. https://doi.org/10.1007/978-3-030-60959-7

[14] Farhan, M. M., Kadum Abd Ali, N., & Hassan, N. Y, 2018. Development the Performance of the Rubbery Discharge Part in Flexo-Pump System, Journal of Engineering and Applied Sciences, vol.13, Issue (24), pp. 10148-10157.

[15] K. Akella and N. K. Naik, "Composite armor - A review," J. Indian Inst. Sci., vol. 95, no. 3, pp. 297–312, 2015.

[16] J. Noinart *et al.*, "Post-harvest maturation of Hevea brasiliensis latex coagula: ranking of the key drivers of the mesostructure and physical properties of natural rubber," *J. Rubber Res.*, vol. 25, no. 1, pp. 5–18, 2022. doi: 10.1007/s42464-022-00146-7.

[17] T. Rashid, M. A. Aleem, S. Akbar, A. Rauf, and M. Shuaib, "Numerical simulation of armor capability of AI2O3 and SiC armor tiles," IOP Conf. Ser. Mater. Sci. Eng., vol. 146, no. 1, 2016. doi: 10.1088/1757-899X/146/1/012049.

[18] T. Balakrishna Bhat & Vemuri Madhu composite armour materials and modules, 2017, Defence Research & Development Organisation, New Delhi – 110 011. ISBN 978-81-86514-90-0.

[19] D. Li, "Layerwise Theories of Laminated Composite Structures and Their Applications: A Review," Arch. Comput. Methods Eng., vol. 28, no. 2, pp. 577–600, 2021, doi: 10.1007/s11831-019-09392-2.

[20] Y. Regassa, G. Likeleh, and R. Uppala, "Modeling and Simulation of Bullet Resistant Composite Body Armor," Int. J. Res. Stud. Sci. Eng. Technol., vol. 1, no. 3, pp. 39–44, 2014.

[21] A. N. Nair, S. Sundharesan, and I. S. M. Al Tubi, "Kevlar-based Composite Material and its Applications in Body Armour: A Short Literature Review," IOP Conf. Ser. Mater. Sci. Eng., vol. 987, no. 1, 2020, doi: 10.1088/1757-899X/987/1/012003.

[22] F. D. O. Braga, T. L. Milanezi, S. N. Monteiro, L. H. L. Louro, A. V. Gomes, and É. P. Lima, "Ballistic comparison between epoxy-ramie and epoxy-aramid composites in Multilayered Armor Systems," J. Mater. Res. Technol., vol. 7, no. 4, pp. 541–549, 2018, doi: 10.1016/j.jmrt.2018.06.018.

[23] C. Lopes Martins Marques, S. R. Kumar, C. Goswami, and R. Verma, "Numerical simulation of armor materials and optimization using gray relational analysis," Mater. Today Proc., vol. 44, no. December, pp. 4717–4730, 2020, doi: 10.1016/j.matpr.2020.10.942.

[24] C. A. C. P. Coelho, F. V. P. Navalho, and P. N. B. Reis, "Impact response of laminate cylindrical shells," Frat. ed Integrita Strutt., vol. 13, no. 48, pp. 411–418, 2019, doi: 10.3221/IGF-ESIS.48.39.

[25] Madeh AR, Abd-Ali NK. Health monitoring of composite car roof failure under effect of different impact velocity. Diagnostyka. 2023;24(4):2023406. https://doi.org/10.29354/diag/174100.

[26] Abd-Ali NK, Madeh AR. Structural analysis of functionally graded material using sigmioadal and power law. Diagnostyka. 2021;22(4):59-65. https://doi.org/10.29354/diag/144171. http://www.diagnostyka.net.pl/Issue-4-2021,10664

[27] Madeh AR, Abd-Ali NK. The stress analysis effect on structural health monitoring in the graded shell. Diagnostyka. 2022;23(3):2022302

[28] Peifeng Su, Miaomiao Li, Qingli Dai, Jiaqing Wang, Mechanical and durability performance of concrete with recycled tire steel fibers, Construction and Building Materials, Volume 394, 2023, 132287, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2023.132287.