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IMPROVEMENT OF MECHANICAL PROPERTIES OF THE RUBBERY PART IN CEMENT PACKING SYSTEM USING NEW RUBBER MATERIALS

NABEL KADUM ABD-ALI[1,*], MALIA M. FARHAN[2], NADA Y. HASSAN[2]

[1]Department of Materials Engineering, College of Engineering,
University of Al-Qadisiyah, Iraq
[2]Technical Engineering College, Baghdad, Middle Technical University, Iraq.
*Corresponding Author: nabel.abdali@qu.edu.iq

Abstract

An investigation has been made to predict the development of the rubbery part of cement packing system, which is within the final stage of the production line in Kufa Cement Factory. This rubber part provides a certain amount of pressure to push the cement material to final packaging under 180°C and maximum pressure about 10 bar, where suffer from damage and rapid failure due to working conditions such as heat, friction, and pressure, adding to the difficulty of replacing it, which requires the suspension of the production line in full. Various types of rubber have been used in different proportions with silica carbon black. also, anti-ozonant, accelerators, softening and vulcanized materials were used to improve the traditional recipe E1. The results showed the superiority of the suggested recipe C2 with (5% neoprene rubber, 95% butyl rubber, carbon black N330 100%), where the tests results such as tensile, tear, compression set, resilience and abrasion test were (18.4 MPa, 7.4 MPa, 9%, 28% and 0.44%) opposite (17.4 MPa, 5.07 MPa, 3.6%, 47.5 % and 0.97 %) for traditional recipe E1, respectively. The new suggested recipe gave an increase in the rubbery part life from 8 hours to 19 working hours under the same conditions and that officially documented.

Keywords: Butyl rubber, Carbon black, Cement packing, Mechanical properties, Neoprene rubber, Silica.

1. Introduction

Natural rubber is available in the countries of Southeast Asia and those countries are the main sources for it [1]. Mixing two or more types of rubber to reach a mixture with specific specifications is an approved procedure in practical research. Rubber is also mixed in its various phases with each other to arrive at specific properties [2]. Also, many studies have shown that the addition of reinforcement or fillers materials causes the improvement of many properties, especially physical ones such as hardness and rebound [3]. Other agents were used for same purpose such as cure activator (ZnO) were used as a traditional and nanoparticles effectively with rubber recipes to improve physical and mechanical properties [4].

The choice of the elastomer recipes additives is linked closely to the type of specifications to be investigated. Particles of carbon blacks advancing distinctive properties such as chemical, heat, and resistance of weathering, lightweight, low thermal expansion, electro-conductivity are commonly used with both polar and nonpolar rubbers to improve tensile strength, elongation, strength of tear, modulus, abrasion, and resilience [5]. Elastomers are blending together to achieve new properties to differ from those of individual, natural rubber is not mingling with synthetic rubber such as styrene-butadiene rubber and that led to rearranged of components rubber recipes [6, 7].

Silica provides unique properties of abrasion, strength of tear, resistance of aging and comparing with carbon black. Also, the silanol groups at elevated temperatures, present on the surface of silica may attach to a number of chemical groups that present in rubber recipes [8-10]. Despite the chemical composition of fillers Identifies many of their physical properties such as density, thermal conductivity, refractive index, it is usually of little importance for the final properties, which are more affected by shape and particle size. Crystalline silica is often used when high resistance of abrasion is needed. Also, it is believed that too soft fillers can themselves fracture or delaminate under applied stresses and can act as critical defects in special cases. Particulate fillers also need to be stable at the temperatures of polymers processing, which can be as high as 350°C, when most fillers are stable at higher temperatures [11].

Generally, the function of the reinforcement material is to improve the final vulcanized rubber strength. While inactive fillers do not primarily affect the dynamic properties of the vulcanized rubber, but include volume, colour, absorption of sound or radiation. The use of active fillers in rubber recipes signifies an improvement in the modulus and the properties like tensile and tear strength in addition to resistance of abrasion. The effect of these materials is important for the dynamic properties of the polymers and the behaviour under variable loads, where the active particles are able to interact with the matrix of elastomer and forming chemical or physical polymer links. Also, the factors that determine the capability of reinforcement are, Van der Waal forces between filler and polymer, beside the chemical crosslinks or chemisorption's depends on to the surface of filler. Also, filler surface effect on the mechanical interlocking of the polymer [12]. Moreover, elastomer performance becomes less predictable when operates near the service temperature range limits, while upper this limit, may be undergo irreversible chemical changes. The polymer backbone may break, or adjacent molecules of polymer may crosslink, causing rigidity of products and reducing the properties of

performance. Also, the relationship between temperature and reaction rate of reactions of the first order may be used as a guide in predicting products life [13].

The current study focused on extend the service life of this important part that reach to 8 hr. by the use of different types of natural and synthetic rubbers such as styrene butadiene rubber, neoprene rubber, butyl rubber and various types of reinforcing materials such as carbon black and silica and suitable vulcanizing materials in specific proportions with the aim of developing the mechanical performance of the engineering application subject of study depending on the properties of those materials and the accumulated practical experience of the specialized industrial companies in addition to the scientific research published in the field of specialization.

2. Experimental Work

The current study deals with the rubber part of cement packing system that push the liquefied cement by air under hard working conditions where the maximum pressure is about (10 bar) during the process of packing each side with a period of time not exceeding five seconds (5 sec.) and the temperature of the liquefied cement resulting in friction due to the flow of cement to reach maximum values about (180°C). Fill condition shall be within five second and fill the tank shall be 75% to avoid loss of cement, in addition to leaving volume for indoor air and the amount of air inside (by the air compressor) is equal to the cement output. The factors that cause damage to the rubbery part are heat, pressure, and corrosion. The heat produced by colliding balls with each other to grind the cement and cause sputtering while abrasion is increased due to leakage of cement. Figure 1 illustrates the cement packing system cover and its rubbery part.

Fig. 1. Cement packing system cover and its rubbery part.

The traditional rubber recipe (or standard recipe), which makes the rubber part of cement packing system recorded the highest operation time about (8 hr.). during the current study, to develop the design of this recipe in order to increase operation time to reduce the times of maintenance and times of breakdown of the packaging system as well as reduce efforts during the process of replacement. The present study included the physical properties, cure characteristics, dynamic mechanical properties, using two carbon black grades Fast Extrusion Furnace (N550), High Abrasion Furnace (N330) in additional to single chain silicates (SiO_3) where the influence of fillers properties. The effect of different vulcanization system was correlated to the rubber properties to understand the performance of a model cement packing system rubbery compound. The formulations selections have been done on the basis of standard recipe formulations, scientific research and experimental

history and recipe design through rubber and filler selection procedure by weight percentages.

2.1. Materials

The present work includes four groups of recipes (E, B, R and C) to choose the best ingredients or the most appropriate one by optimum most tests, because it is difficult to find a recipe to achieve priority in all tests results absolutely. The first procedure of material selection (group E) focused on rubber and reinforcement or filler agent type, while the second procedure (group B) deals with rubber and new reinforcement or filler agent type in addition to accelerator agent. Group R and C dealt with rubber, filler, accelerator, and vulcanizing agent types.

Group E divided into two groups, the first (E1 to E3) and the second (E4 to E6) with rubber loading percentage Standard Malaysian Rubber/Styrene Butadiene Rubber (NR/SBR), where the rubber loading percentage (30/70, 50/50, 70/30) for E1, E2 and E3 respectively, the second group of E's with same rubber loading sequence (30/70, 50/50, 70/30) for E4, E5 and E6, respectively. The other components amounts of these recipes such as ZnO, antioxidants, polymerized 2-2-4-trimetyl-1-2-dihydroquinoline (TMQ), wax as an anti-ozonant agent, dutrix oil as a softening agent, sulphur, peptizer agent (renicit), stearic acid as a stabilizer agent, antiozonant, N-isopropyl-N′-phenyl-1,4-phenylenediamine (IPPD) and accelerators, N-cyclohexyl-2-benzothiazyl sulphonamide (CBS) with same loading percentage 80, 15.3, 60.7, 200, 13.4, 9, 41, 40.7 and 1.2 for each one respectively. The reinforcement agent in first group of E's was carbon black N550 with loading percentage (100 %) of rubber loading, while the second grope with (50%) in addition to offset ratio of silica, SiO_3 (50%). The recipe E1 represents the standard recipe that used in the factory to produce the rubbery part and the other recipes represent the current attempts to produce better specifications in terms of performance.

In group B, the same types of rubber blending (NR/SBR) with different loading percentage (88/12), with reinforcement agent carbon black N330 with loading percentage (100 %) of rubber loading for recipe B1, and with (50%) for recipe B2 in addition to offset ratio of silica, SiO_3 (50%). The other components amount of these recipes such as ZnO, TMQ, wax, dutrix oil, sulphur, retarder agent CTP.100, renicit, stearic acid and IPPD with loading percentage 84, 20.8, 42, 143, 10, 1.5, 3, 42 and 31 for each one respectively, and with loading percentage (9%) form N-oxydiethylene-2-benzothiazyl sulphenamide (OBTS) as a fast accelerator agent for each recipe.

In group R, the same types of rubber blending (NR/SBR) with different loading percentage (60/40) for each recipe, and with same reinforcement agent carbon black N550 with loading percentage (100 %) of rubber loading for recipe R1, and with (50%) for recipe R2 in addition to offset ratio of silica, SiO_3 (50%). The other components amount of these recipes such as ZnO, sulphur, CTP.100, renicit, cobalt Striate, stearic acid and IPPD with loading percentage 181, 30, 1, 2.2, 227, 33 and 41 for each one respectively, and with loading percentage (1% and 0%) form N, N'-dicyclohexyl-2-benzothiazole sulfenamide (DCBS) as a Medium speed accelerator agent for recipe R1 and R2, respectively.

In group C, other types of rubber blending neoprene rubber/butyl rubber (CR/IIR) with different loading percentage (5/95), and with same reinforcement

agent carbon black N330 with loading percentage (100%) of rubber loading for recipes C2 and C3, and with (50%) for recipe C1 in addition to offset ratio of silica, SiO_3 (50%). The other components amount of these recipes such as ZnO, special vulcanizing resin (vulcarsin) and castor oil with loading percentage (100, 195 and 95%) for each one, respectively.

2.2. Laboratory tests methods

Many tests were conducted on the rubber recipes designed during this study were carried out at laboratories of Al-Dewaniyah tire factory and Babylon tire factory. All tests were performed according to standards approved tests. Hardness test ASTM D1415 and D 2240, tensile test ASTM D 412, tear test- type B ASTM D 624, compression set test ASTM D 395 and B.S.903, method B, resilience test B.S. 903and abrasion test according to ASTM D 5963. Also, other apparatuses were used to complete these tests such as Wallace sample press for tensile and tear test, nicking device for tear test, thermal hydraulic press and two-roll mill mixer. Also, mixing mill with batch weight 4.5 kg. and 15-20 drive hours power. Figure 2 shows the mixing process in two-roll mixer.

Fig. 2. Two-roll mixer.

3. Results and Discussion

3.1. Hardness test results

Figure 3 shows hardness tester, where all values of the hardness vary from 30 to (88 IRHD) as shown in Fig. 4. and all these recipes have acceptable hardness values except recipe C1, C3 (58 and 60 IRHD) respectively, in addition to recipes R1 and R2 that have the highest value (85 and 88) respectively. The results of recipes C1 and C3 may be related to type of synthetic rubber used chloroprene (neoprene) with hardness range (40-90 shore A) with other good mechanical properties, also butyl rubber with hardness range (40-80 shore A). The increase in the proportion of plasticizers (Castor oil) from (95gm to 190gm) and the proportion of vulcanization material (vulcarsin) from (195gm. to 200gm.) may have a clear effect on the result of recipe C3. The high results of the recipes R1 and R2 may be related to percentage of carbon black loading above (70%) respect to the rubber loading. Also, the increase in hardness value in recipe R2 it may be due to adding silica with percentage (50%) of total carbon black loading (N550).

Fig. 3. Hardness tester.

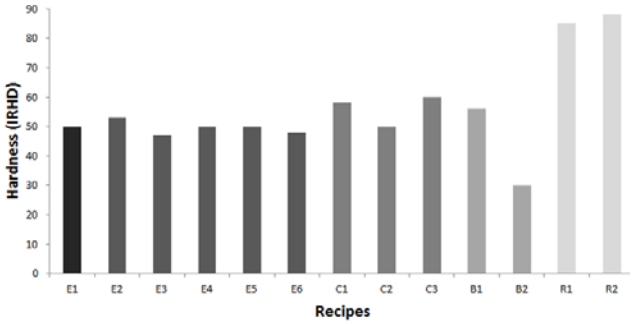

Fig. 4. Hardness test results.

3.2. Tensile test results

3.2.1. Tensile strength (MPa)

Figure 5 shows the tensometer machine for tensile, elongation and tear test. Figure 6 shows the results of the tensile property, which ranged between the lowest value (8.4 MPa) in the recipe E4 and the highest value (24.3) in the recipe B1. During the first three recipes of group E, the improvement in this property was remarkable, which may be due to increase the proportion of natural rubber. Natural rubber crystallizes upon straining where strain induced crystallization lends outstanding green strength, tack, and good crack growth resistance at intense stresses [14]. It is also possible to note the decline in this property, which may be due to the use of alternative filler material (SiO_3). The results of group B can also be attributed to the same reasons, and the ratio of high natural rubber about (88%) and use of reinforcement material carbon black (N330) in recipe B1 may explain the improvement in the tensile properties of this recipe and these results compatible with previous study by Al-Alkawi et al. [15]. Also, the results of the group (R) ranged between (14.7 MPa) and (11.6 MPa) for R1 and R2 respectively, which can be attributed to the material nature of these recipes and their components (rubber and filler) and the characteristics of each component.

Fig. 5. Tensile test machine

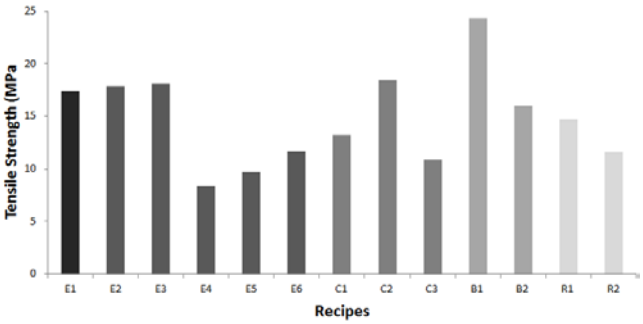

Fig. 6. Tensile test results.

The vulcanization process of group C was done by the resin while the other recipes were vulcanized by sulphur. This is due to the nature of the current

engineering application, which is working under certain conditions such as pressure and friction, as well as the temperature exceeding 180°C and for long time periods (pro-long). The recipe C2 have the highest value in same group (18.4 MPa) and this may be caused by the nature and percentage of rubber used in addition to use of carbon black N330, where the void volume (empty space) within the agglomerates and aggregates, usually expressed as the volume of Di-butyl phthalate (DBP) absorbed by a given amount of carbon black, is described as a (carbon black structure). The larger the DBP value mean the higher structure of carbon black [16]. Also, the result of other recipes C1 and C3 may be related to use of other nature and amount of material compounds in these recipes and behaviour of this material.

3.2.2. Elongation at break (%)

Figure 7 shows that all the readings of the recipes gave acceptable results for the elongation, except the group R recipe R1 and R2, which has already been characterized by high hardness which may be the reason for preventing the elongation of samples and this may be caused by the high percentage of reinforcement material CB N550 above (70% pphr) as mentioned in hardness test results.

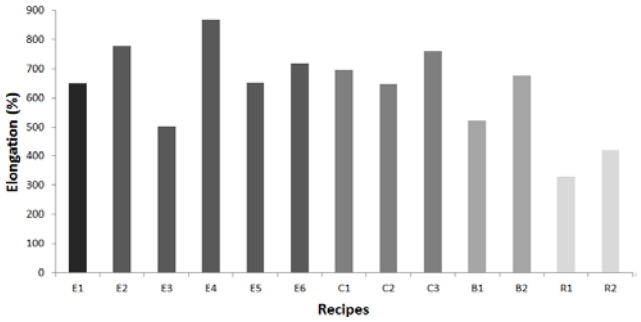

Fig. 7. Elongation at break.

3.3. Tear test results

Figure 8 shows the results of the tear test ranged between the lowest values (2 MPa) in recipe E5 and the highest values (11 MPa) in recipe B1. The acceptable result of recipe E2 and E3 (5.6 and 5.8 MPa) may be related to NR loading in these recipes (50% and 70% pphr) respectively, in addition to the effect of other material compound such as reinforcement material carbon black N550. Also, the recipe C2 have the highest value in this group (7.4 MPa), and the decreasing in the tear strength of recipe C3 may be due to the increase in the proportion of some material compound such as plasticizers and softening material, which in turn reduced the property of the tear and rapid crack growth of tear test. In group R, it is possible to explain the reason for the low resistance of recipes R1 and R2 for the same reasons mentioned previously, which is the increase of the loading ratio of reinforcing material carbon black (N550) and filler material (SiO_3) to more than 70%. Also, good results for group C may be related to specific properties of rubbery compounds of these recipes. The recipe B1 have the highest value, and this may be related to loading percent of natural rubber (NR) about (88% pphr) in addition to the effect of property of reinforcement material carbon black (N330). The stereoregularity of natural rubber which makes it susceptible to crystallization vs. straining, the crystalline domains of natural rubber restrict the free ends of segments

in chains (act as crosslinking of vulcanizing agents, sulphur) then this lends some improvements without reinforcement, while SBR is amorphous and un-crystallized vs. straining and these results compatible with previous studies such as Harper [17] and Shaw et al. [18].

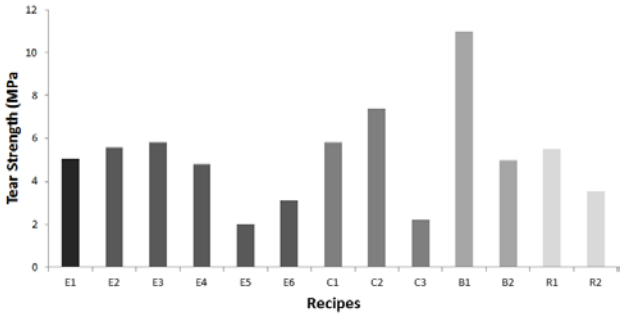

Fig. 8. Tear test results.

3.4. Compression test results

Figure 9 shows the compression tester and the results of the compression test range between the lowest values (3.1%) of the recipe (B1) and the highest values (11%) of the recipe C3 as shown in Fig. 10. The decreasing of in compression set value indicates the material's ability to return to its original state before exposure to compression forces. The best value here in group B, recipe B1. The highest value in recipe E4 may be related to the use of filler (SiO_3) in addition to the (NR/SBR) ratio, and specific properties for each one. Also, filler (SiO_3) perhaps the reason behind the increasing in result of recipe B2 and R2.

Fig. 9. Compr. tester

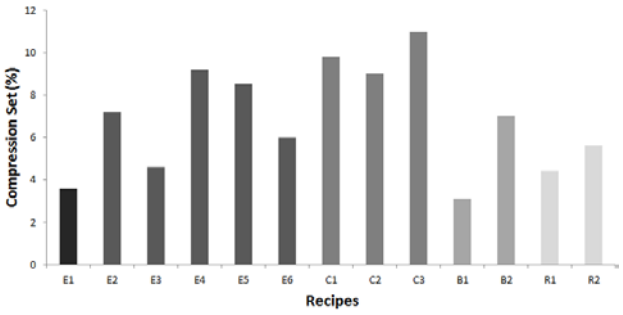

Fig. 10. Compression test results.

3.5. Resilience test results

Low resilience values indicate to the material's ability to absorb shock, so the quality of the rebound is inversely proportional to the hardness of the rubber compounds. Through the results of the recipes in the group E, which can be seen as the quality of the resilience of the recipes which includes natural and synthetic rubber. In addition to the superiority of synthetic rubber on natural rubber in heat resistance, while the decrease in the results of the last recipes E4, E5 and E6 can be

attributed to increased hardness due to the addition of filler material (SiO_3). It is also possible to note the improvement in the rebound properties for the group C in general and recipe C2 specially, and this may be due to the distinctive properties of the rubber used in these recipes (butyl and neoprene), as well as the positive effect of the reinforcement material (carbon black N330) compared with other recipe for which silica was added as a filler material. Butyl is a copolymer of isobutylene with a small amount of isoprene to provide curing sites with a low T_g (about -70°C). Also, it has distinguished stability of aging due to the saturation state [19]. All these explanations can justify the results of group B as well as the group R, and it is possible to note the poor results of group R may be due to the increase in the loading of carbon black (about 70% pphr) on the one hand, as well as the increase of the vulcanization and plasticization material on the other hand. Figure 11 shows resilience tester while Fig. 12 shows resilience tests results.

Fig.11.Resilience tester.

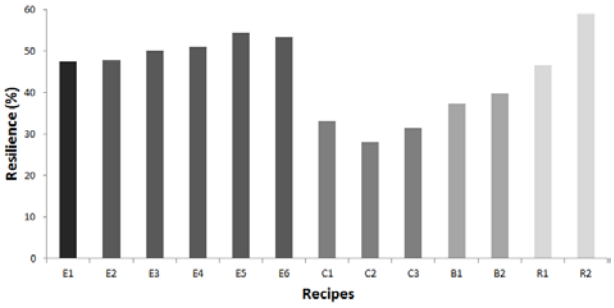

Fig. 12. Resilience test results.

3.6. Abrasion test results

The results of this test represent the amount of loss due to abrasion, so the low values indicate to the ability of these compounds to resist abrasion and thus represents the quality of these recipes for this property. Through group recipes E, the gradual improvement of abrasion can be observed with the increase in the proportion of synthetic rubber. It is also possible to observe the decline of this characteristic due to the addition of a filler (SiO_3) to the same recipes. The quality of this property can also be seen in the group C, may be due to the rubber nature of these preparations as well as the type of reinforcing material (N 330). While the decrease in this property may be related to the addition of an alternative filler. Also, the results of group B and group R may be attributed to the same reasons discussed in the previous tests and the results of group R for this property may be more acceptable than the previous test (resilience test). Figure 13 shows abrasion tester and Fig. 14 shows abrasion test results. A key advantage carbon black, as modification of surface is not a prerequisite for distinctive dispersion and distinctive interphase properties. A further advantage of carbon black to silica is its superior resistance to abrasion, rheological properties and flexing and these may be compatible with the results of Al-Hartomy et al. [20], Ulfah et al. [21], Stelescu et al. [22], Abd-Ali et al. [23] and Abd-Ali et al. [24].

Fig. 13. Abrasion tester

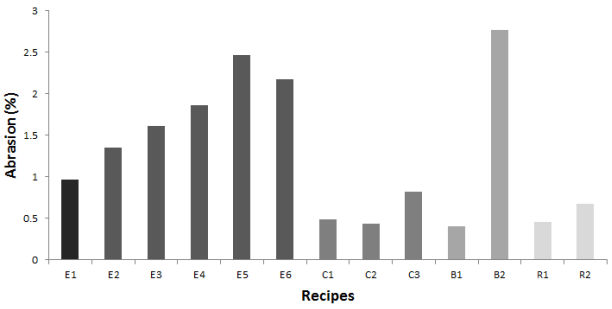

Fig. 14. Abrasion test results.

Figure 15 illustrates comparison between two best recipes C2 and B1, in addition to standard recipe E1 and show the ability of C2 to improve the mechanical properties and performance as optimum one in most laboratory tests.

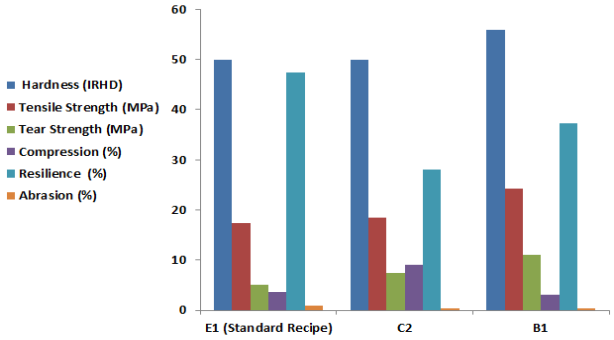

Fig. 15. Comparison between best recipes vs. standard recipe.

The current work is an integral part of a master's thesis for the same researchers, noting that the previous part of this work has been published previously [25] in addition to other work on the mechanical properties and mechanical behaviour of rubber compounds [26].

4. Conclusions

The results of this work can be referred to several conclusions, the most important of which are:

- **Group E**: Recipe E2 with blend (50% NR, 50% SBR) was the best in most tests results such as tensile, elongation at break, tear, and resilience test. These results were related to increase in NR ratio and fully reinforcement by carbon black N550 with general loading about 50% pphr. low speed accelerator (CBS) was used with these recipes.
- **Group C**: Recipe C2 with blend (5% CR, 95% IIR) was the best in most tests results such as hardness, tensile, elongation at break, tear, resilience, and abrasion test. These results were related to the use of neoprene and butyl rubber and fully reinforcement by carbon black N330 with general loading about 50% pphr.

- **Group B**: Recipe B1 with blend (88% NR, 12% SBR) was the best in most tests results such as tensile, tear, compression, resilience, and abrasion test. These results were related to increase in NR ratio and fully reinforcement by carbon black N330 with general loading about 50% pphr. Fast speed accelerator (OBTS) was used with these recipes as a new additive.
- **Group R**: Recipe R1 with blend (60% NR, 40% SBR) was the best in most tests results such as tear, resilience, and abrasion test. These results were related to fully reinforcement by carbon black N550 with general loading about 70% pphr. Cobalt Striate used in these recipes with medium speed accelerator (DCBS).

In addition, the engineering application of this recipe in the Kufa Cement Factory by using it in manufacturing of the rubber part in cement packing system proved this result by improving the performance of this part and the change in the working life of this part from (8) working hours to (19) hours under hard conditions by recipe C2, which reflects the ability of the recipe performance and higher quality compared to the other recipes, especially the standard recipe currently used. Also, the authors are looking forward to using a fiberglass mat as well as fine linen fibers to improve performance specifications.

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