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Development the Performance of the Rubbery Discharge Part in Flexo-Pump System

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Abstract: Polymer chains are reinforced by the addition of suitable reinforcement materials to improve performance properties such as mechanical, physical and chemical properties. Presents research include experimental test such as specific gravity, rheological and flexing test were used to evaluate several rubber recipes contain natural and synthetic rubber. The reinforcing materials such as silica and carbon black were also used to enhance the bonding of the rubber chains. N, N-dicyclohexyl-2-benzothiazole-sulfonamide, N-cyclohexyl-2-benzothiazyl sulphenamide and (N-oxydiethylene-2-benzothiazole sulfenamide were used in addition two types of vulcanization system. The experimental and theoretical results were evaluated and compared with the results of the standard recipe that currently used to produce the rubbery part of flexo-pump system and showed that the increasing in the reinforcing material loading led to increasing the specific gravity, also the increasing in natural rubber loading led to increase the flexing resistance. Moreover, the use of specific grade of black carbon (such as N330) causes the similar improvement while the use of silica in specific quantities (50% of carbon black) gives different effects for all attempts. Some of new recipes gave excellent results comparing with the standard recipe. Some recipes were the safest because they have the highest scorch time ts_2 while other recipe probably considered is the most economical because it has the lowest curing time ts_{90}.

Key words: Rheology, flexing, benzothiazole, sulfenamide, rubber butyl, chloroprene, carbon black, silica

INTRODUCTION

There are many local researchers who have researched on polymeric recipes and its contents such as Lukashevich and Najim (2017), Al-Essa *et al.* (2010), Ibrahim *et al.* (2014), Neeran and AlaaHassen (2017). The reinforcement of the polymer matrix by the addition of reinforcing material is a common industrial practice to improve the performance properties of rubber recipes. This reinforcement depends on the relationship and on the interaction between the reinforcement materials and the polymer matrix. It also depends on the degree of homogeneity of the reinforcement material within that matrix and the properties of the reinforcement material itself (Stelescu *et al.*, 2016). The interaction of rubber and filler has been studied the effects of failure in rubber compounds where reinforcement material adding cause decreasing of the freedom of the rubber chains because of the adsorption and interaction of non-deformable filler onto rubber materials. Upon an applied stresses the rubber compounds should carry out the grand total strain, therefore, the global strain is lower than the local strain produced by the system (Ismail *et al.*, 2011; Ulfah *et al.*, 2015).

One of the mechanisms by which fillers reinforces elastomers is that assume the filler effect is to increase the chains number which shared the loads of a broken of polymer chain. Fillers used in industries may be classified by properties, color and sources. The sources basis could be organic or inorganic. Inorganic fillers such as barytes, calcium carbonate, silica, etc. while the organic fillers are high styrene resins, phenolic resins, etc. (Egwaikhide *et al.*, 2013; Peng, 2007). The most important influencing factors in the reinforcement materials are the size of the particles and their surface area which ultimately affect the properties of the recipe and its performance. The use of silica particles as alternative substrates has become popular in the rubber industries to find certain properties. The surface of silica particles has a specific characteristic compared to the surface of carbon black particles when interacting with elastomers. This characteristic is shown by different dynamic properties with viscosity significantly observed when silica is used which led us to use liquid factors to improve process capacity and enhance properties (Ulfah *et al.*, 2016, 2016; Zafarmehrabian *et al.*, 2012; Al-Hartomy *et al.*, 2015; Surya *et al.*, 2013). Other

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studiesdiscussed evaluate the correlation of the reinforcing degree and the viscosity of the rubber recipes, these studies concluded that the higher viscosities are reached when the filler effective volume increases (Ansarifar *et al*., 2007; Gheller *et al*., 2016).

A curing system by sulphur is a commonly used in the industry of rubber with several advantages such as lower toxicity, lower cost, good compatibility with additives and expected vulcanization properties. In curing process by sulphur more than one accelerators are used to complete the cure by submit effect of synergistic curing. An primary accelerator can be used and then complete the vulcanization process with a secondary accelerator. The accelerators influence strongly not only the cure characteristics of rubber compound and safety only but also its final properties. Although, increase level of accelerator can increase the cross-link density (Hewitt and Ciullo, 2007; Khang and Ariff, 2011; Choi and Kim, 2015; Susamma *et al*., 2004).

During the current research three types of accelerators were used individually in each time also two types of vulcanization system in addition to the use of reinforcing materials such as carbon black and silica with rubber recipes that were used which included natural rubber and synthetic rubber such as styrene butadiene rubber butyl and neoprene rubber with vulcanized systems suitable for the properties of these materials. The practical and theoretical results of the rubber recipes prepared during the study were used in addition to the standard recipe for the purpose of determining the improvement in the performance under specific working conditions for the case study which was the discharge rubbery part of the flexo-pump system in one of the cement factory.

Literature review: The current study deals with the rubbery discharge of flexo-pump system that push the liquefied cement by air under specific conditions. Pressure and temperature conditions was variety during process until reach to (10 bar) approximately. The temperature increase as a results of friction due to the flow of cement and due to the heat of the cement itself till reach large values ranging between (150-180°C). Standard rubber recipe that use today to manufacture rubbery part of flexo-pump system works well for only 8 h. This study attempts to develop the performance of this recipe under the same working conditions to ensure high performance within longer periods of work and to achieve maintenance hours, efforts and less emergency stops. Figure 1 and 2 show tuner of the two reservoirs and damaged rubbery part.

Present research included several attempts to develop, including the use of the same types of rubber used in the standard recipe but in different proportions in addition to the use of new types of rubber such as butyl and neoprene rubber with the use of appropriate materials in vulcanization process. Also, silica with a certain compensatory rate was used instead of carbon black as a reinforcement and filler material. The selections of formulations have been done basis on standard recipe, scientific research, practical experience and experimental history and recipe design through rubber and filler selection procedure by weight percentages.

Fig. 1: Tuner of the two reservoirs

Fig. 2: Rubbery part

MATERIALS AND METHODS

Several material were used in present research include elastomers (Natural Rubber (NR), synthetic rubber, Styrene Butadiene Rubber (SBR) butyl (IIR) and neoprene rubber (CR), fillers such as Carbon Black (CB), Fast Extrusion Furnace FEF (N550), high abrasion furnace HAF (N330) and Silica (Sio_3), antioxidants such as polymerized 2-2-4-trimetyl-1-2-dihydroquinoline (TMQ), antiozonant such as IPPD, paraffin wax. accelerators: N-cyclohexyl-2-benzothiazyl sulphenamide (CBS), fast

Table 1: Materials selection of grope E

Recipe No. materials	Standard Recipe (E1) 30% NR 70% SBR	Recipe (E2) 50% NR 50% SBR	Recipe (E3) 70% NR 30% SBR	Recipe (E4) 30% NR 70% SBR	Recipe (E5) 50% NR 50% SBR	Recipe (E6) 70% NR 30% SBR
NR	600	1007	1415	600	1007	1415
SBR1502	1415	1007	600	1415	1007	600
Zincoxide	80	80	80	80	80	80
TMQ	15.3	15.3	15.3	15.3	15.3	15.3
Wax	60.7	60.7	60.7	60.7	60.7	60.7
Dutrix oil	200	200	200	200	200	200
C.B (FEF) 550	1046 (100%)	1046	1046	523 (50%)	523 (50%)	523 (50%)
Sulphur	13.4	13.4	13.4	13.4	13.4	13.4
Renicit	9	9	9	9	9	9
Sio_3	-	-	-	523 (50%)	523 (50%)	523 (50%)
Stearic acid	41	41	41	41	41	41
IPPD	40.7	40.7	40.7	40.7	40.7	40.7
CBS	1.2	1.2	1.2	1.2	1.2	1.2

Table 2: Materials selection of grope C

Recipe No. material	Recipe (C1) 5 (%) CR 95 (%) IIR	Recipe (C2) 5 (%) CR 95 (%) IIR	Recipe (C3) 5 (%) CR 95 (%) IIR
CR	95	95	106
IIR	1950	1950	2110
Zincoxide	100	100	103
C.B (HAF)330	535 (50%)	1070 (100%)	1070(100%)
Sio3	535 (50%)	-	-
Vulcarsin	195	195	200
Oil (Dutrix)	95	95	190

Table 3: Materials Selection of Grope B

Recipe No. materials	Recipe (B1) 88% NR 12% SBR	Recipe (B2) 88% NR 12% SBR
NR	1827	1.827
SBR1502	258	258
Zincoxide	84	84
TMQ	20.8	20.8
Wax	42	42
Oil (Dutrix)	143	143
C.B (HAF)330	1034 (100%)	517 (50%)
Sulphur	10	10
CTP. 100	1.5	1.5
Renicit	3	3
Sio_3	---	517 (50%)
Stearic Acid	42	42
IPPD	31	31
OBTS	9	9

*Total CB loading to rubber (50%)

and medium speed accelerator (N-oxydiethylene-2-benzothiazole sulfenamide OBTS, N, N-dicyclohexyl-2-benzothiazole sulfonamide (DCBS), activators such as Zink oxide, stearic acid, softening aids such as mineral plasticizer oil (aromatic oil), castor oil, vulcanizing agents such as sulfur and vulcarisn. This research includes four gropes (E, C, B and R). Table 1-4 include the material selection to improve the performance under specific conditions.

Table 4: Materials selection grope R

Recipe No. material	Recipe (R1) 60% NR 40% SBR	Recipe (R2) 60% NR 40% SBR
NR	1360	1360
SBR1502	905	905
Zincoxide	181	181
C.B (FEF)550	1634 (100%)	817 (50%)
Sulphur	30	30
CTP. 100	1	1
Renicit	2.2	2.2
Cobalt Steatite	227	227
Sio_3	-	817 (50%)
Stearic Acid	33	33
IPPD	41	41
DCBS	1	-

*Total CB loading to rubber, (70%)

Table 5: Molding conditions

Molding operation	Temp. (°C)	Time (min)
Specific gravity test specimen	160	15
Rheology test specimen	185	6
Fatigue test specimen	145	45

Laboratory tests: Many tests were conducted on the rubber recipes designed during this study, including specific gravity and rheological test that were carried out at laboratories of Babylon Tire factory according to standard (ASTM D 297) by the density meter device, Monsanto-Densitron and (ASTM D 2084) by the Rheology device (Monsanto Rheometer ODR E2000), respectively. Firstly, stiffness decreases as it warms up then it increases due to vulcanization process (Matthan, 1998; Brown, 2006; Anonymous, 2001).

Fatigue failure test covers the finding of cut growth rate of vulcanized rubber recipe when under repeated flexing. It is particularly applicable to tests compounds of rubber by method type B of test methods D 430 by De Mattia machine. Initiation of crack in the test specimen by small cuts in service may rapidly increase in dimension and progress to final failure. Table 5 shows the molding conditions (Anonymous, 2000; Abraham, 2002).

A mill was used which consists of two cast iron rolls with cylindrical shape and approximate batch weight about 4.5 kg and with roll size (Dia.×Length) about (10*20) in.

RESULTS AND DISCUSSION

Some of laboratory tests had been conducted such as specific gravity, rheological test, flexing test and all these tests results were cured out under standard conditions according to ASTM.

Specific gravity test: Figure 3 shows specific gravity test results, it is possible to observe the recipes (R1 and R2) which gave the highest values in this test 1.228 and 1.205, respectively. These results may be attributed to different reasons combine, including the high weight percentage of natural rubber in these recipes which is about 60% natural rubber behaves unique physical and chemical properties where rubber is often modeled as hyper-elastic material and strain crystallizes. Natural rubber is an thermoplastic elastomer when it vulcanized, rubber turns into a thermoset. The final rubber properties depend on the polymer in addition to modifiers and fillers such as carbon black, factice, whiting and others. Molecular weight distribution influences viscosity and elasticity of raw natural rubber and different impurities in raw NR influence the rubber hydrocarbon stability in processing and applications (Kovuttikulrangsie and Sakdapipanich, 2004). The effect of carbon black loading (70%) on the results of this test may be understood through the Table 6 below which shows the particle size, empty space surface area and aggregate size.

Rheological test: The maximum torque values M_H, range from 10 lb-in in stock E5 to 63 lb-in in stocks R1. Also, the values of scorch time t_{s2} range from 0.76 mm in recipe R1 and 5 m.m in recipes C1 and C2 while the values of t_{s90} range from 1.67 mm in recipe B1 and 13.4 m.m in recipe C3. The maximum torque may be used as an indication of the crosslink density of the rubber compound and measure of the stiffness of the compound (Friedrich *et al*., 2005; Markovic *et al*., 2009).

Figure 4-6 show the best value of maximum torque, scorch time and curing time were for stocks R1 (60% NR-40% SBR), C2 (5% CR-95% IIR) and B1(88% NR-12% SBR), respectively. Where maximum torque referred to crosslink density and the long scorch or induction period means high safety of processing and a short cure period is required to avoid over-cure. (CR) has superior resistance to flame and heat, weatherability and adhesion to polar substrates. The micro structure of (CR) is mostly trans-1, 4 and homo-polymer crystallize upon straining, although, it is not as stereo-regular. Also isobutylene rubber (Butyl) is a copolymer with a little amount of

Table 6: Properties of carbon blacks (Anonymous, 2004)

Carbon black grade	Particle size (nm)	DBP (mL/100 g)	Surface area (m^2/g)	Aggregate size (nm)
N330	46	102	80	146

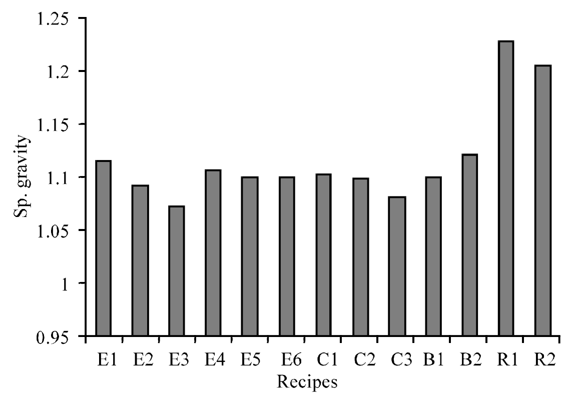

Fig. 3: Specific gravity test results; E1-E3: rubber selection (NR/SBR) and E4-E6: filler selection (CB 550/Silica), C1-C3: rubber selection (CR/IIR) with specific vulcanizing Agent (vulcarisn), B1-B2: rubber and filler selection (NR/SBR) and (CB 330/Silica) with loading percentage 50%; R1-R2: rubber and filler selection (NR/SBR) and (CB 550/Silica) with loading percentage 70%

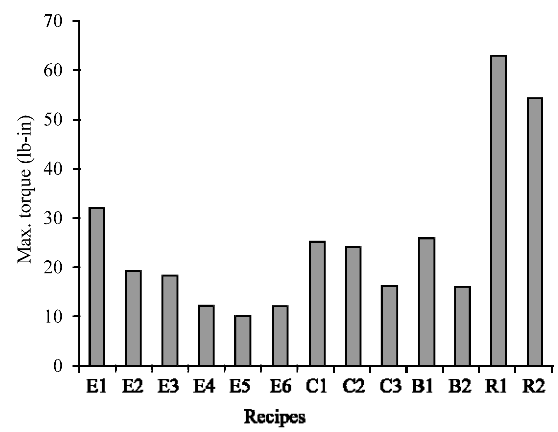

Fig. 4: Rheological test, maximum torque; E1-E3: rubber selection (NR/SBR) and E4-E6: filler selection (CB 550/Silica), C1-C3: rubber selection (CR/IIR) with specific vulcanizing agent (vulcarisn), B1-B2: rubber and filler selection (NR/SBR) and (CB 330/Silica) with loading percentage 50%. R1-R2: rubber and filler selection (NR/SBR) and (CB 550/Silica) with loading percentage 70%

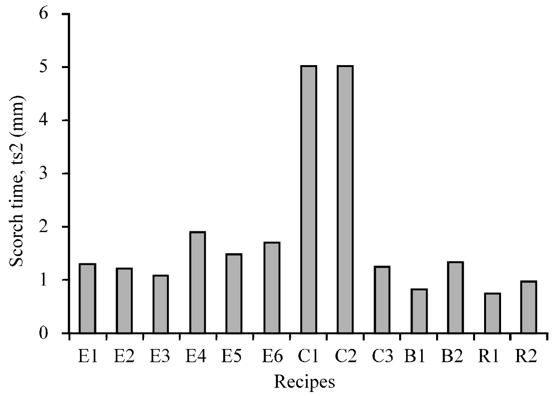

Fig. 5: Rheological test, scorch time: E1-E3; rubber selection (NR/SBR) and E4-E6: filler selection (CB 550/Silica), C1-C3: rubber selection (CR/IIR) with specific vulcanizing agent (vulcarisn), B1-B2: rubber and filler selection (NR/SBR) and (CB 330/Silica) with loading percentage 50%. R1-R2: rubber and filler selection (NR/SBR) and (CB 550/Silica) with loading percentage 70%

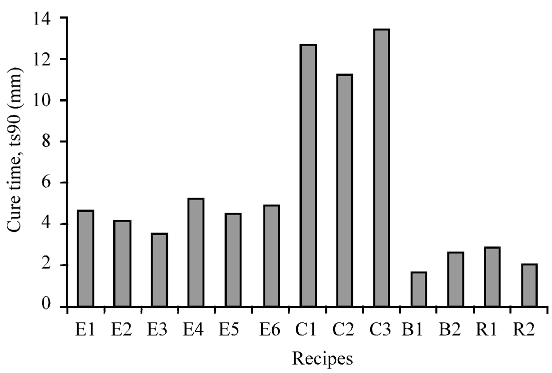

Fig. 6: Rheological test results, curing time: E1-E3; rubber selection (NR/SBR) and E4-E6: filler selection (CB 550/Silica), C1-C3: rubber selection (CR/IIR) with specific vulcanizing agent (vulcarisn), B1-B2: rubber and filler selection (NR/SBR) and (CB 330/Silica) with loading percentage 50%; R1-R2: rubber and filler selection (NR/SBR) and (CB 550/Silica) with loading percentage 70%

isoprene to provide sites for curing. Butyl rubber cannot be cured with sulfur vulcanization is often inactive. Polymethylol phenolic resins with metallic chlorides get excellent cross-linked materials with good resistance to thermal effects (Alan, 2001).

Increase percentage of NR in stock R1 (about 60%) blended with SBR (about 40%) reinforced with carbon black N550 with specific properties as in Table 7 may be the cause of increase cross-linking density and reduce the scorch time.

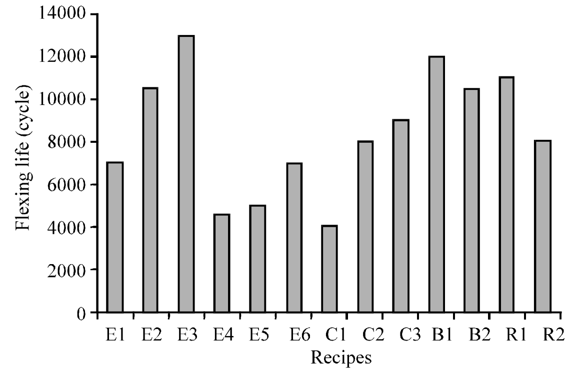

Fig. 7: Flexing test results: E1-E3; rubber selection (NR/SBR) and E4-E6: filler selection (CB 550/Silica), C1-C3: rubber selection (CR/IIR) with specific vulcanizing agent (vulcarisn), B1-B2: rubber and filler selection (NR/SBR) and (CB 330/Silica) with loading percentage 50%; R1-R2: rubber and filler selection (NR/SBR) and (CB 550/Silica) with loading percentage 70%

Table 7: Properties of carbon blacks (Anonymous, 2004)

Carbon black grade	Particle size (nm)	DBP (mL/100 g)	Surface area (m^2/g)	Aggregate size (nm)
N550	93	121	41	240

Recipe B1 have the best (short) value of curing time 1.67 m.m where the lowest value mean less power and research with economic benefits in addition to safe over-cure. Also recipes C1and C2 have the best (long) value of scorch time (5 m.m) where this time referred to the safety period during complete processing.

Flexing fatigue test: Figure 7 illustrates the fatigue tests results for stressed recipes at 60°C. Recipe E3, recipe C3, recipe B1 and recipe R1 gate the best results comparing with other recipes in same group. All of these results may be relevant for the same reasons that explained previously such as nature of rubber and filler.

The increasing of filler aggregate size led to specific improvement in resistance to fatigue failure. In synthetic rubber (non-crystallizing) like SBR, CR and IIR the fatigue properties is much more dependent on the size of initial crack or flaw as shown in Fig. 8. Such type of elastomers is longer in life at small deformities and life decreases with increasing severe conditions. Also, the increasing in temperature causes a significant reduction in internal viscosity, resulting in a reduced fatigue life and that led to the sharp increase crack growth rate as shown in Fig. 9 (Abd-Ali, 2013; Al-Alkawi *et al*., 2013a, b).

The interaction between rubber matrix and reinforcements materials affects the quasi-static properties of the recipes in addition to the fatigue life. Integration of

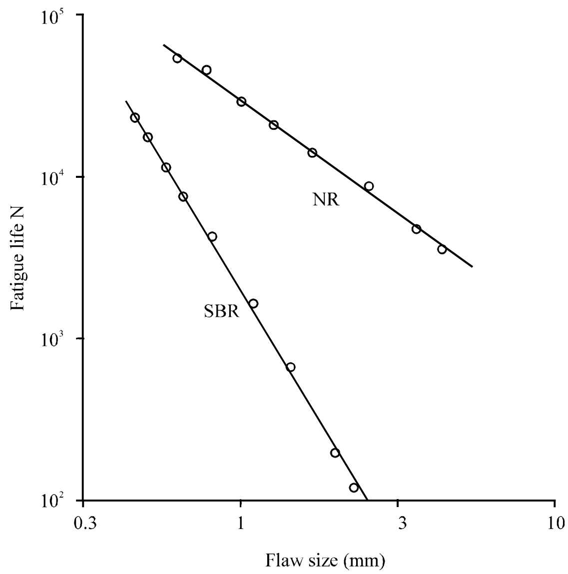

Fig. 8: Life vs. flaw size

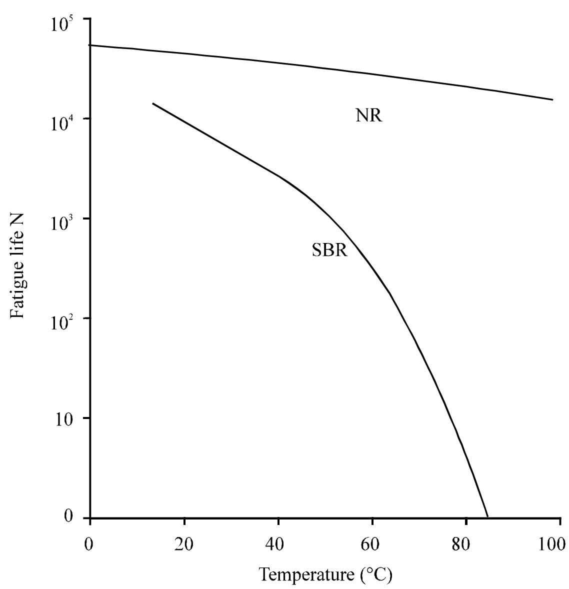

Fig. 9: Life vs. temp

these materials into natural rubber recipes useful to increase modulus in addition to hinder propagation of crack and the reduction in propagation of crack related to localized crystallization occurring in the recipe due to areas of highly restricted polymer near the tip of crack as well as in high constraint regions due to the particles of filler (South, 2001). All these results were compatible with previous studies such as Al-Alkawi *et al*. (2013a, b) and Farhan and Moosa (2017a, b).

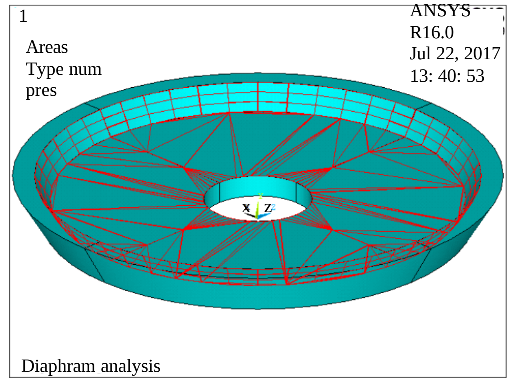

Fig. 10: Area exposed to pressure

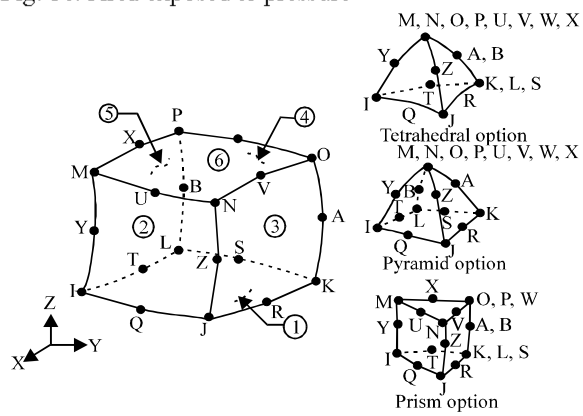

Fig. 11: SOLID 186 structural

The engineering application of recipe C2 in the Kufa Cement Factory explained the development of discharge rubbery part by improving the performance and the change in operation time from (8-19) working hours which reflects the ability of this recipe performance and higher quality compared to the other recipes, especially the standard one.

Finite Element Analysis (FEA): Computer simulations reproduce behavior of a system that using a mathematical model that have become a good tool for the mathematical modeling of many natural systems. Simulation may be used to explore and gain new insights into new technology and to estimate systems performance of very complex for analytical solutions (Steven, 2007).

Present research deals with rubbery discharge part of flexo-pump system in Kufa Cement plants under specific boundary conditions where pressure reach to (10 bar) and temperature reach to (180°C). The internal face as illustrated in Fig. 10 bears these conditions specially. Mooney-Rivlin 2-parameters with a higher order 3-D (SOLID186) in Fig. 11, 20-node and having three degrees

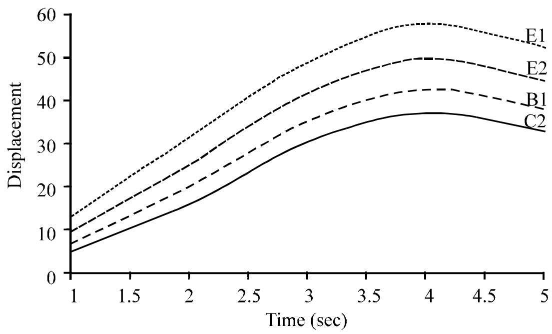

Fig. 12: Disp. response under transient load

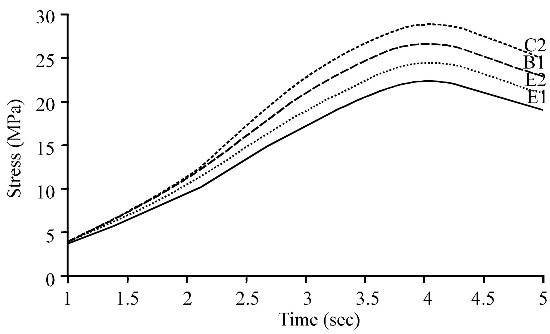

Fig. 13: Von-misses response under transient load

of freedom per node. Also, it supports stress stiffening, plasticity, creep, hyper-elasticity, large deflection with large strain capbilities.

Figure 12 and 13 show the theoretical solution results where it seems all these results compatible with experimental results and gave same indications through illustrate the behavior of selected recipes. The minimum displacement at 5th second was found in recipe C2 (32.78 mm) and maximum value of the displacement is (52.16 mm) for recipe E1. Also, at 5th second the minimum value was found in recipe E1 (19 MPa) and maximum stress value was found in recipe C2 (24.8 MPa) and all these results may be attributed to same reasons that mentioned in experimental research previously. The slight increase in theoretical readings is due to the fact that the theoretical solutions do not take into account the defects and flaw in the material but treat them as ideal material as well as the accuracy of the reading considerations and time for the stresses and displacements which cannot be strictly determined during the experimental tests.

Figure 14-21 illustrates numerical response for best selected recipes. The engineering application of these recipes in Kufa Cement Factory in manufacture of the rubber discharge part in the flexo-pump system. this results improved the performance of this part and the

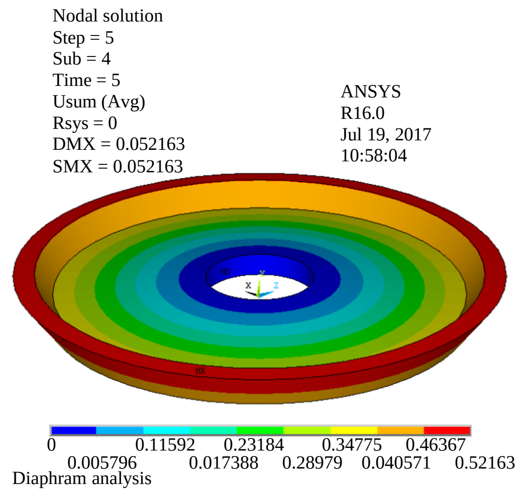

Fig. 14: Disp. at 5th sec for E1 (30 NR/70 SBR)

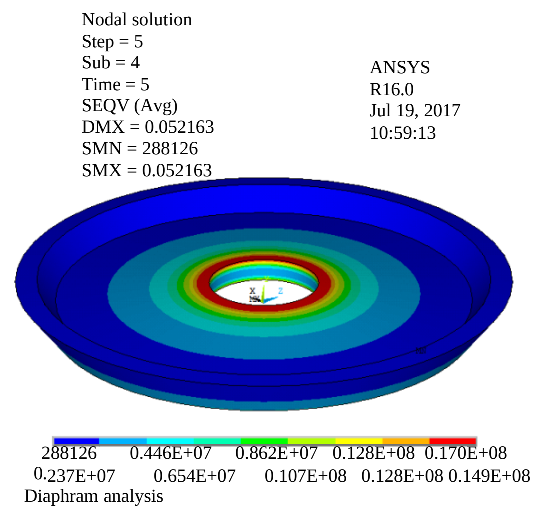

Fig. 15: Stress at 5th sec for E1 (30 NR/70 SBR)

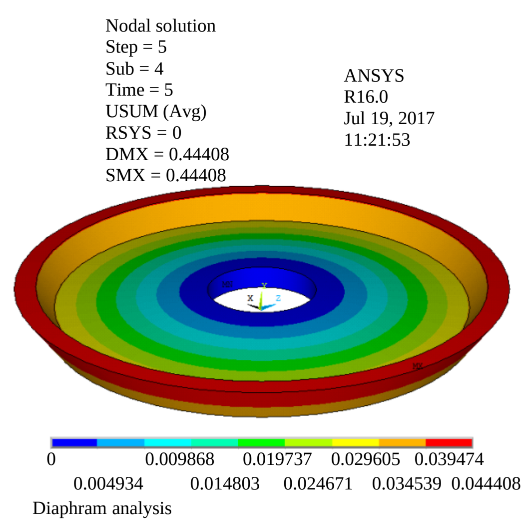

Fig. 16: Disp. at 5th sec for E2(50 NR/50 SBR)

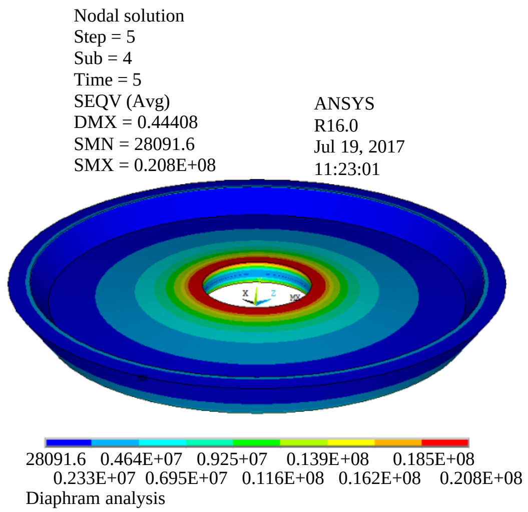

Fig. 17: Stress at 5th sec for E2(50 NR/50 SBR)

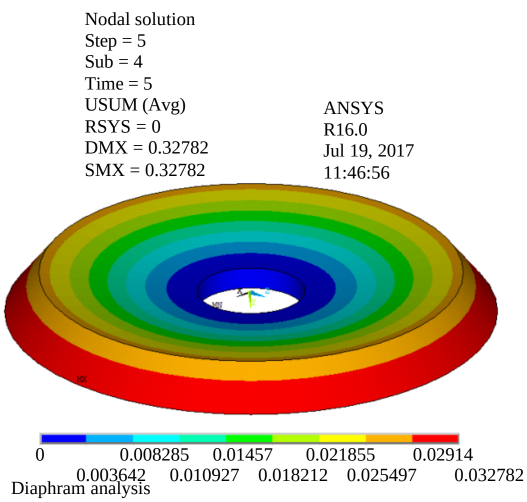

Fig. 18: Disp. at 5th sec for C2(5 CR/95 IIR)

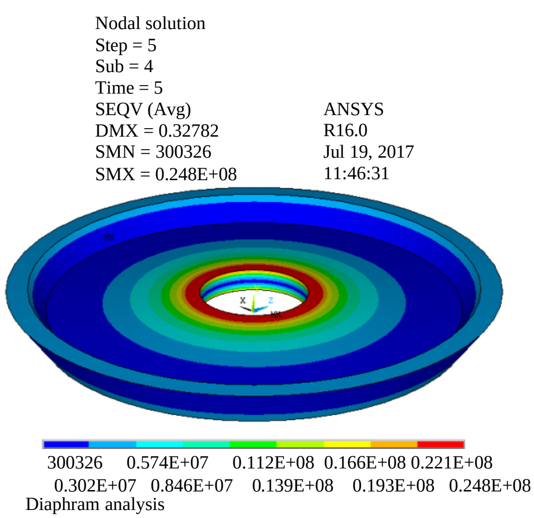

Fig. 19: Stress at 5th sec for C2(5 CR/95 IIR)

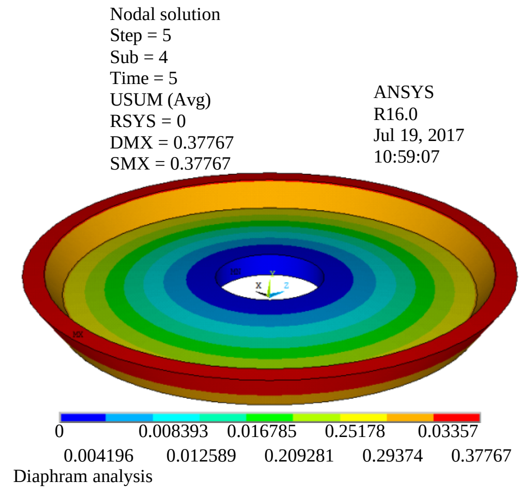

Fig. 20: Disp. at 5th sec for B1(88 NR/12 SBR)

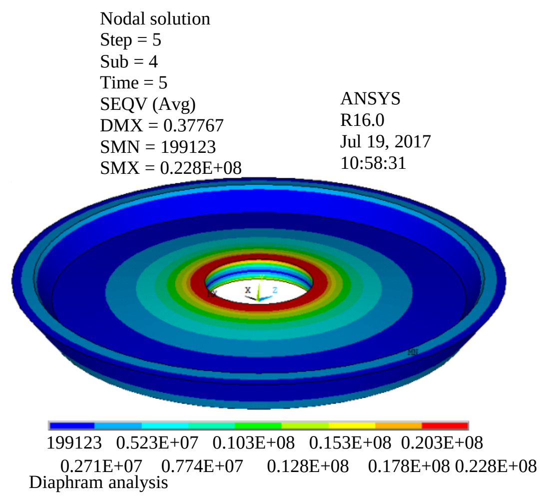

Fig. 21: Stress at 5th sec for B1(88 NR/12 SBR)

working life from 8-19 working hours by using recipe C2 specially and this refer to the ability of the recipe performance compared to the other recipes.

CONCLUSION

The present study led to an important conclusions such as the increase in the loading ratio of the reinforcing material increased the value of the specific gravity which can be seen in the group R as well as the effect of increasing the percentage of natural rubber. Group C recipes (especially, C1 and C2) are the safest because they have the largest scorch time ts_2 while recipe B1 probably considered is the most economical because it has the least curing time ts_{90}.

The increase in natural rubber loading has led to increased flexing resistance and the use of specific grade of black carbon (such as N330) causes the improvement of these properties while it was observed that the use of silica in large quantities gives a different effect.

The use of different types of synthetic rubber (such as neoprene and butyl rubber coupling) in the recipe of rubbery part with different vulcanize system gave excellent results.

Generally, during this research, a number of recipes have been obtained which give better results and better performance comparing with standard recipe of the discharge rubbery part in flexo-pump system. Also, addition supplementary part for this research, selected recipe C2 as optimum recipe with high performance characteristics through several tests such as tensile, tear, hardness, resilience, compression and abrasion test.

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