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Increasing the Working Life and Performance Improvements of Down Whole Mud Motors Using Nanocomposite Elastomer

Mehrdad Izadi[1], Mohammad Tabatabaee Ghomi[1] and Gholamreza Pircheraghi[2]

1. Technology Development Institute, Academic Center for Education, Culture and Research (ACECR)

2. Department of Materials Science and Engineering, Sharif University

tabatabaee@usc.ac.ir

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INTRODUCTION

The most important tools for drilling directional and horizontal oil and gas wells are downhole mud motors, which are designed, based on Moineau pumps [1]. The power section is the most important part from the viewpoint of performance efficiency and working life [2]. Moreover, the power section consists of rotor and stator. In addition, stator is a lining elastomer within the metal housing. Both the stator and rotor are helical where the stator always has one more helix than the rotor. Fig.1 shows the power section in different lobe configurations. Therefore, the used elastomer is subject to mechanical and thermal stresses in the high pressure and high temperature of drilling fluid environment, consequently, the p probability of stator failure is more than other parts [3]. Also, the deformation and elastomer swelling in drilling fluid are the other factors that accelerate elastomer degradation [4,5].

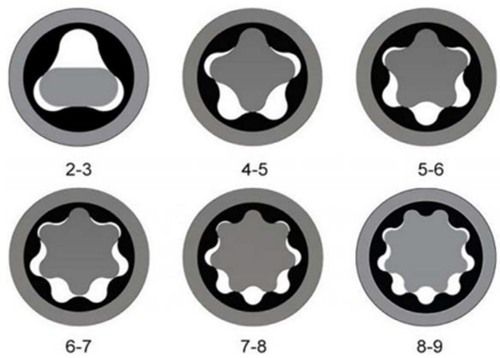

Figure 1: The cross section of the mud motor in different lobe configurations.

Reinforcement of the elastomer, which increase the motor working life, reduces the number of drill string trip times for changing the motor, and in turn will reduces the working days of the drilling rig. In the drilling industry, there is a direct relation between time and cost, so increasing the working life of the motor leads to a considerable cost reduction in this expensive industry [6]. Several attempts were down to extend the elastomer life by developing the design or materials used [7,8]. Various elastomers are used to produce stator lining, among which nitrile-based elastomers such as NBR are widely used. A comparison of various types of elastomers used in motors has been done, and NBR shows better outcome on other types. Drilling fluids are often divided into water-based, oil-based and polymer-based types. Among these, oil-based drilling fluid has the highest effect on the elastomer degradation [9]. Usage of heavier fluid and the higher temperature of the well precipitate the degradation of the elastomer [5]. NBR showed satisfactory resistance to nonpolar fluids and is the most accepted rubber as the elastomer of motor [10,11]. In the Mud motor, mechanical and thermal cyclic stresses are the main reason of elastomer failure. The mechanical stresses are due to interactional and continuous contact of rotor and elastomer and mud pressure. The more swelling of elastomer by drilling fluid, the more stress between rotor and elastomer will occur, so the dimensional stability of elastomer is a comparative important factor.

Thermal stresses are due to the gradient wellbore temperature and as well as hysteresis effect. This heat generation effect is caused by the interaction of rotor and elastomer regarding viscoelastic properties of elastomer. Moreover, the generated heat traps inside the elastomer due to its low thermal conductivity. In combination with the downhole temperature, this heat buildup can seriously degrade the elastomer’s physical and mechanical properties.

Nanocomposites are a new group of composites in which at least one dimension of the filler materials is in the nanometer range [12]. Considering the need to increase the elastomer mechanical and thermal properties, nanoclay has been selected as the nano reinforcement in several studies [13]. The clay known as montmorillonite consists of plates with an inner octahedral layer sandwich between two silicate tetrahedral layers. The purpose of this work is to improve elastomer resistance against mechanical and thermal stress by using NBR/clay nanocomposite instead of pure NBR. In this study, different loads of nanoclay have been added to the nitrile rubber. Afterwards, the effect of nanoclay loading on thermal, mechanical, and barrier properties behaviors of elastomer has been studied. To investigate the effect of nanoclay on performance and properties of elastomer, swelling, hardness, tensile strength, tear resistance, compression set, dynamic mechanical thermal analysis, and fatigue tests have been conducted regarding to working conditions of mud motors in downhole.

EXPERIMENTAL PROCEDURE

NANOCOMPOSITE SAMPLE PREPARATION

Nitrile rubber containing 33 percent acrylonitrile with the specific gravity of 0.98 was supplied from SIBUR Company. The cloisite 30b with high polarity to make strong crosslinking with polymer chains selected [14,15]. Different percentages of nanoclay were mixed with the NBR from 0 to 10 PHR by adding 2.5 PHR in each steps. So 2.5 PHR NC stands for the nanocomposite which contains 2.5 PHR nanoclay.

The compound was mixed for 12 minutes at 60 ^{o}C in a Brabender internal mixer with rotational speed of 50 rpm. Then in order to eliminate its bubbles, the compound was rolled by an open two-roll mill.

The rubber compound was cured in a hot press machine at 165 ^{0}C, and under the pressure of 10 MPa. The curing time was obtained from Rheometer apparatus based on ASTM D-5289 standard. The results have shown that the curing time is reduced with the increase in the nanoclay percentage. This effect can be attributed to the ammonium groups in the organoclay and facilitation of the formation of crosslinks. For aging, the oil-based drilling mud has been selected with the mud weight of 85 pounds per cubic foot and funnel viscosity of 43 seconds per quart. The required samples for each test were put in oil based drilling mud at 75 ^{0}C for 72 hours. The temperature and working hour have been chosen according to the temperature of most wells and the drilling working hours.

RESULTS AND DISCUSSION

The swelling properties of the compounds in the drilling fluid have been demonstrated in Fig. 2. The fluid intake percentage of the compounds has been considerably reduced by increasing nanoclay loading which has been observed in previous research [16,17].

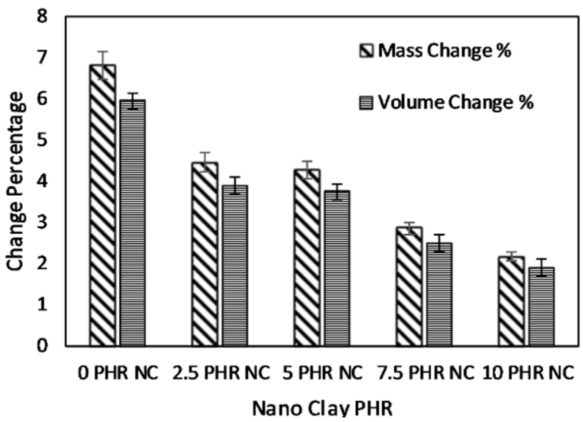

Figure 2: The comparison of weight and volume change in oil-based mud.

Fig. 3 depicts the rising trend of hardness with increasing the clay content. It is predictable that hardness increases by adding Nanoclay for both samples, before aging and after aging test. It is due to the stronger bond between the elastomer chains and the silicate layers [18].

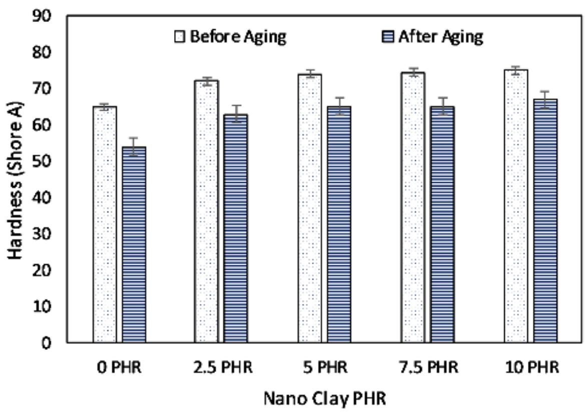

Figure 3: The comparison of the results obtained from hardness test (Shore A) for different compounds.

The strain stress diagram is presented in Fig. 4. The Young's Modulus and also tensile strength and maximum elongation at break are comparable factors. This shows the increased modules for different compounds of nanoclay.

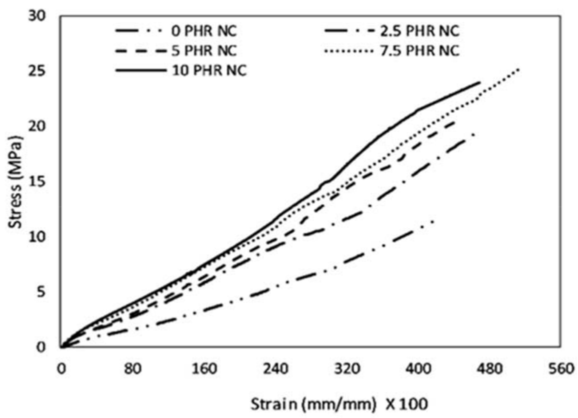

Figure 4: The strain stress diagram for different compounds of nanoclay.

Fig. 5 demonstrates tear strength, which has proved to be also a useful indicator for mechanical strength of specimens.

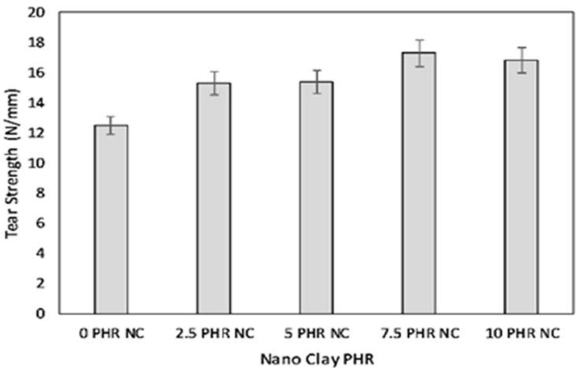

Figure 5: The comparison of tear strength.

The compression set which is one of the main properties of rubbers has been shown in Fig. 6. Aligned polymer chains due to the presence of nanoclay, lead to a reduction in the permanent elastomeric deformation [19].

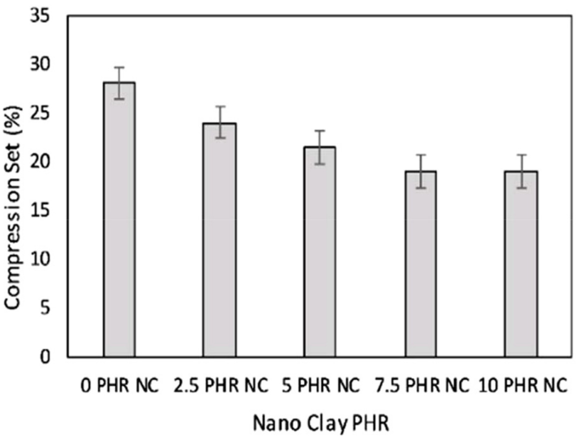

Figure 6: The comparison of compression set in different samples.

Increase in thermal strength becomes possible by increasing the storage modulus compared to loss modulus, which in turn decreases the stored hysteresis heat buildup.

Under cyclic loading due to hysteresis losses and low rubber thermal conductivity, the temperature of rubber increases. This leads to degradation of its physical and mechanical properties. The following Figs. 7 and 8 show the temperature dependence of storage modulus and tan delta for specimens. Nanocomposite compounds have shown a considerable increase in storage modules compared to neat rubber, as expected. By increasing the nanoclay loading, a reduction in tan delta peak is observed. The tan delta reduction causes a reduced heat buildup and demonstrates fewer damping properties for nanoclay composite compound.

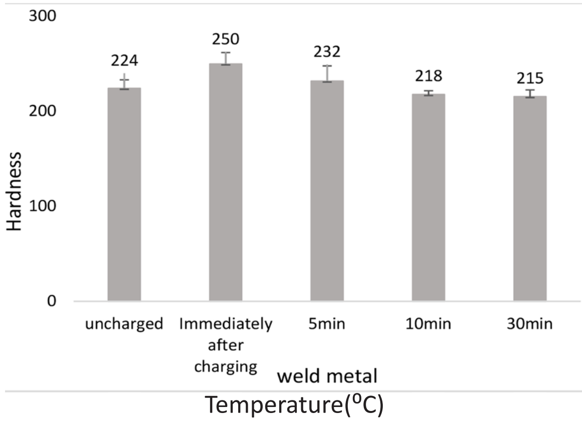

Figure 7: The comparison of storage module in different samples.

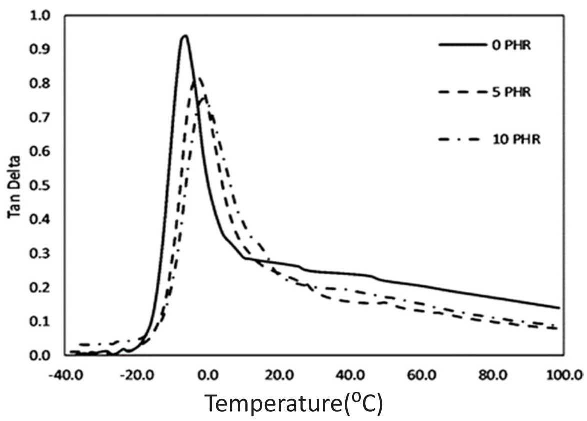

Figure 8: The comparison of tan delta in different samples.

DIFFERENT SAMPLES

Fatigue life of aged elastomer has been measured based on ASTM 4482 standard. Strain percentage was set on 60, 90, 120, and 150%. Results were derived by averaging between six samples. Increasing fatigue life of nanocomposite is clear in Fig. 9 for each definitive elongations.

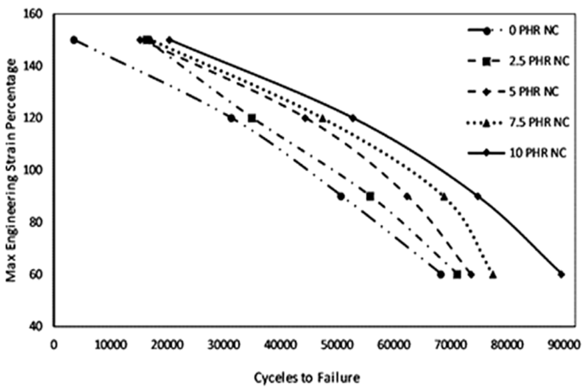

Figure 9: Cycles to failure under different strain.

There is a significant increase in the fatigue life with increasing nanoclay content. Chunking occurs when the rotor wear stator in its circular movement, and elastomer has reached the fatigue limit. Small pieces break free so the drilling mud could leak between rotor and stator so efficiency of power section decreases. This leads to ROP decrement and to maintain efficiency and rate of penetration, operators will normally push motors harder and increase flow rate, further accelerating the motor working life time. Therefore, the elastomer has to have ample fatigue strength to withstand the cycling loads. Moreover, stalling the motor is most probable, and pulling out and changing the mud motor are inevitable.

CONCLUSIONS

In hardness, tensile, and tear resistance tests, the increase in the mechanical strength of the new samples was confirmed. The specimens showed a significant increase in their strength particularly by the addition of small amounts of nanoclay in first steps. No remarkable changes are recognized in the mechanical properties with the addition of more than 7.5 wt.% of nanoclay, which suggests the agglomeration of silicate layers in high content. On the other hand, fatigue life of nanocomposite samples is highly improved. The thermal strength of the motor was investigated by conducting the dynamic mechanical test, which showed that because of the viscoelastic properties of rubber, the increase in the thermal strength of the proposed nanocomposite can be ensured. It is concluded because of loss coefficient, which corresponds to the enhancement of heat accumulation in the elastomer, is reduced. In addition, the geometry of the nanocomposite remains more stable than pure elastomer that is resulted from swelling and compression set tests. The more stable geometry of the elastomer under the effect of the drilling fluid and the temperature of the well, the more its efficiency and working life increase. Based on the mentioned points, the proposed nanocomposite from the nanoclay strongly increases mud motor performance and working life. Consequently, reducing the drilling times by increasing the working life of the motor is directly related to the reduction of drilling costs.

REFERENCES

[1]. Nguyen T., Al-Safran E., Saasen A. and Nes O. M., *"Modeling the design and performance of progressing cavity pump using 3-D vector approach,"* Journal of Petroleum Science and Engineering, Vol. 122, pp. 180–186, 2014.

[2]. Zhang J., Liang Z. and Han C., *"Failure analysis and finite element simulation of key components of PDM,"* Engineering Failure Analysis, Vol. 45, pp. 15–25, 2014.

[3]. Zhang Z., Yu X., Zhao W., Zhang L. and Zhang R., *"Exploring wear detection method for special drilling parts in liquid media,"* International Journal of Refractory Metals and

Hard Materials, Vol. 61, pp. 249–258, 2016.

[4]. Delpassand M. S., *"Stator life of a positive displacment downhole drilling motor,"* Journal of energy resources technology, Vol. 121, No. 2, pp. 110–116, 1999.

[5]. Han C., Zhang J. and Liang Z., *"Thermal failure of rubber bushing of a Positive displacement motor: A study based on thermo-mechanical coupling,"* Applied Thermal Engineering, Vol. 67, No. 1–2, pp. 489–493, 2014.

[6]. Lukawski M. Z., Anderson B. J., Augustine Ch., Capuano Jr.L. E., Beckers K. F. and J. Tester W., *"Cost analysis of oil, gas, and geothermal well drilling,"* Journal of Petroleum Science and Engineering, Vol. 118, pp. 1–14, 2014.

[6]. Lukawski M. Z., Anderson B. J., Augustine Ch., Capuano Jr.L. E., Beckers K. F. and J. Tester W., *"Cost analysis of oil, gas, and geothermal well drilling,"* Journal of Petroleum Science and Engineering, Vol. 118, pp. 1–14, 2014.

[7]. Zhang J., Han C. and Liang Z., *"Physics of failure analysis of power section assembly for positive displacement motor,"* Journal of Loss Prevention in the Process Industries, Vol. 44, pp. 414–423, 2016.

[8]. Azizov A., Davila W., Nnanna O. and Rizen A., *"Positive displacement motor innovation drives increased performance with PDC in unconventional plays,"* In Spe/iadc Middle East Drilling Technology Conference and Exhibition, Society of Petroleum Engineers, pp. 1–15, 2011.

[9]. E. K. Ross K. C., Pugh T. and Huycke J., *"Performance characteristics of drilling equipment elastomers evaluated in various drilling fluids,"* In Spe/iadc Drilling Conference. Society of Petroleum Engineers, SPE 21960, 1991.

[10]. Hendrik J., *"Elastomers in mud motors for oil field application,"* in Corrosion 97. NACE International, 1997.

[11]. Liu J., Li X., Xu L. and Zhang P., *"Investigation of aging behavior and mechanism of nitrile-butadiene rubber (NBR) in the accelerated thermal aging environment,"* Polymer testing, Vol. 54, pp. 59–66, 2016.

[12]. Pavlidou S. and Papaspyrides C. D., *"A review on polymer-layered silicate nanocomposites,"* Progress in polymer science, Vol. 33, No. 12, pp. 1119–1198, 2008.

[13]. Santamaría P., González I. and Eguiazábal J. I., *"Mechanical and barrier properties of ternary nanocomposite films based on polycarbonate/ amorphous polyamide blends modified with a nanoclay,"* Polymers for Advanced Technologies, Vol. 26, No. 6, pp. 665–673, 2015.

[14]. Tolooei S., Naderi G., Shokoohi S. and Soltani S., *"Elastomer nanocomposites based on NBR/BR/nanoclay: Morphology and mechanical properties,"* Journal of Polymer Engineering, Vol. 33, No. 2, pp. 133–139, 2013.

[15]. Islam M. S., Masoodi R. and Rostami H., *"The effect of nanoparticles percentage on mechanical behavior of silica-epoxy nanocomposites,"* journal of nanoscience, Vol. 2013, pp. 1–10, 2013.

[16]. Nah C., Ryu H. J., Han S. H., Rhee J. M. and Lee M. H., *"Fracture behaviour of acrylonitrile-butadiene rubber/clay nanocomposite,"* Polymer International, Vol. 50, No. 11, pp. 1265–1268, 2001.

[17]. Paul D. R. and Robeson L. M., *"Polymer nanotechnology: Nanocomposites,"* Polymer,

Vol. 49, No. 15, pp. 3187–3204, 2008.
[18]. Mahallati P., Arefzar A. and Naderi G., "Thermoplastic elastomer nanocomposites based on PA6 / NBR," International Polymer Processing, Vol. 25, No. 2, pp. 132–138, 2010.
[19]. Alberola N. D., Benzarti K., Bas C. and Bomal Y., "Interface effects in elastomers reinforced by modified precipitated silica," Polymer Composites, Vol. 22, No. 2, pp. 312–325, 2001.