Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Characteristics And Mechanical Strength Of Tube Collars Made From Natural Rubber And EPDM

Dr. Arote Keshav Chandrakant[1], Dr. Pande Ashish Madhukarrao[2] , Dr. Lande Yogesh Dileep[3]

[1,2,3]Lecturer, Department of Mechanical Engineering, Amrutvahini Polytechnic Sangamner, Maharashtra, India.

Tube collars must be mechanically strong, long-lasting, and flexible to be employed in a broad range of industrial applications. It is the purpose of this research to examine the properties and tensile strength of tube collars made of NR and EPDM. The tensile strength, elasticity, and resilience of natural rubber are legendary, while the weather resistance, thermal stability, and chemical inertness of EPDM are unparalleled. A variety of ratios (70:30, 80:20, 90:10, and 100:0) phr are seen between natural rubber and ethylene propylene diene monomers. A number of substances are prepared for use, including the activator, coactivator, filler, accelerator, antioxidant, and vulcanizing agent. Vulcanization and compounding were the methods used to conduct the trials. Vulcanized rubber's mechanical qualities are affected by the ratio of natural rubber to ethylene propylene diene monomer, according to the findings of the experiment.

Keywords: Natural rubber, Ethylene propylene, Tube collars, Mechanical Strength, Tensile

I. Introduction

The automotive, construction, and industrial sectors are just a few that rely heavily on tube collars. Because of their critical roles in sealing, vibration dampening, and structural support, these components must be mechanically strong and durable to ensure proper functioning. What makes tube collars unique and how long they last are the material you choose. The mechanical strength, flexibility, and resilience of NR and EPDM, two of the most popular elastomers, make them ideal for a variety of applications. Natural rubber has great flexibility, abrasion resistance, and a high tensile strength.[1] It is resistant to irreversible damage from mechanical stress and distortion. Unfortunately, there are certain places where natural rubber can't be used because of how fast it deteriorates under ozone, UV light, and high temperatures. On the other hand, EPDM is a great choice for long-term durable applications because to its chemical inertness, exceptional thermal stability, and outstanding weather resistance. However, when it comes to applications that require a high level of flexibility, EPDM isn't the best choice because it isn't as elastic as natural rubber.[2]

Tensile strength, elongation, and resistance to compression set are three elements that determine the mechanical strength of tube collars. Tube collars made of natural rubber are more elastic and can absorb impact forces because they have a higher tensile strength and elongation at break. Applications that need vibration dampening and shock absorption greatly benefit from this characteristic. However, EPDM tube collars provide improved mechanical stability over time due to their superior resistance to permanent deformation.

When testing tube collars for their capacity to retain their form under continuous pressure, compression set is a crucial metric to consider. Despite its great elasticity, natural rubber can lose its shape under long-term stress due to its relatively high compression set. Because of this, sealing applications may experience reduced performance or even leakage. However, because to its lower compression set, EPDM is more suited for uses requiring long-term sealing, such gaskets, pipe fittings, and automobile seals.[3]

In uses where tube collars are subjected to continual mechanical wear and friction, abrasion resistance is an additional critical component of mechanical performance. Machinery, conveyor systems, and dynamic components benefit greatly from natural rubber's exceptional performance in high-friction environments. EPDM's superior chemical and environmental resilience more than makes up for its modest abrasion resistance. Because of this, it is an improved option for uses where resistance to oils, chemicals, and harsh weather is vital. When it comes to outdoor and industrial applications, the environmental resistance of tube collars is an important factor in determining their lifespan. When exposed to heat, ultraviolet light, and ozone, natural rubber quickly degrades, eventually breaking on the surface and failing mechanically. On the other hand, EPDM maintains its structural integrity even when subjected to extreme heat, ozone, and ultraviolet light over extended periods of time. The material's mechanical qualities remain unchanged in temperatures between -40°C and 120°C, making it ideal for use in outdoor and automotive contexts.

Sealing, vibration dampening, and structural strengthening are some of the many uses for tube collars in the automobile industry. Natural rubber tube collars are commonly employed in engine mounts, suspension systems, and shock absorbers owing to their great elasticity and impact resistance. But in hot climates, you'll have to replace them often because of how easily they degrade from heat and chemicals. In contrast, EPDM tube collars are widely used in applications requiring high levels of heat resistance and chemical stability, such as brake system components, weather seals, and radiator hoses. In industrial contexts, the decision between natural rubber and EPDM relies on the unique needs of the application. Natural rubber-based tube collars are favored in high-dynamic systems with repetitive stretching and compression motions, such as hydraulic and pneumatic systems. When durability in the face of heat, oxidation, and chemicals is paramount, as it is in chemical plants, outdoor equipment, and power transmission systems, EPDM tube collars are the way to go.[4]

Hybrid elastomers, improved material reinforcing, and additive changes are the materials of the future for tube collars. Both natural rubber and EPDM are subject to ongoing research aimed at enhancing their mechanical qualities and resilience to environmental factors.

Advancements in composite materials and new rubber formulas are projected to further enhance the performance, durability, and sustainability of tube collars.

Properties of Natural Rubber and EPDM

There are a number of industrial uses for elastomers such as natural rubber and ethylene propylene diene monomer (EPDM). Despite sharing a reputation for resilience and adaptability, the mechanical, environmental, and chemical properties of the two materials make them uniquely suited to certain fields. While latex, a milky fluid produced from rubber plants, is the source of natural rubber, EPDM is a synthetic elastomer composed of ethylene, propylene, and a tiny quantity of diene monomer, which gives it improved characteristics for certain applications.

Because of its great elasticity, durability, and tensile strength, natural rubber is highly prized. This material is perfect for uses that need a great level of flexibility and toughness because to its remarkable ability to both stretch and return to its original form. Because of its low compression set, it can withstand repeated deformation without losing its shape or functionality. Tires, seals, conveyor belts, and shock absorbers are just a few examples of the many items that benefit greatly from the exceptional strength and flexibility offered by natural rubber.[5]

When compared, EPDM's dimensional stability and resistance to permanent deformation more than make up for its modest tensile strength. Applications requiring constant performance under pressure are well-suited to EPDM because, in contrast to natural rubber, it does not readily lose its shape when exposed to continuous stress. In addition, EPDM is a lightweight alternative to natural rubber due to its reduced density, making it a good fit for businesses that value durability over bulk. When durability and weather resistance are paramount, it finds widespread use in roofing membranes, industrial gaskets, and automobile weather seals.

In terms of how well they withstand environmental conditions, EPDM stands in stark contrast to natural rubber. When exposed to air and sunshine, natural rubber may deteriorate due to oxidation, ozone, and ultraviolet radiation. Because of the increased likelihood of cracking and mechanical property loss with extended contact to the elements, it is not recommended for use in outdoor applications. Further reducing its usefulness in harsh climates is the fact that natural rubber has a tendency to harden at very low temperatures and soften at very high ones.

Conversely, EPDM can withstand a great deal of exposure to the elements and other forms of environmental damage. It is relatively unaffected by long-term exposure to ozone, intense heat, and ultraviolet light. Roofing materials, weatherproof seals, and electrical insulation are just a few examples of outdoor applications that benefit greatly from EPDM's long-term durability. EPDM maintains its pliability at extreme temperatures (-40°C to 120°C), therefore it keeps performing well even in the most extreme environments.

Natural rubber has good chemical resistance to water and mild acids, but it may be easily damaged by oils, petroleum-based fluids, and powerful chemicals. Because of this, it can't be used in fields where exposure to such chemicals is necessary. Since it retains its pliability and mechanical strength in dry, non-reactive conditions, it is best suited for uses that do not include strong chemicals.[6]

EPDM, on the other hand, is very long-lasting in chemically aggressive settings because to its exceptional resistance to acids, alkalis, and polar solvents. In industrial environments, where contact to harsh chemicals is unavoidable, this material is recommended since it does not deteriorate when exposed to hydraulic fluids, steam, or brake fluids. Oils and hydrocarbons derived from petroleum are incompatible with EPDM and may cause it to expand and deteriorate over time.[7]

Tires for cars, conveyor belts, work gloves, and athletic gear are just a few of the many uses for natural rubber, which is highly pliable and resistant to impact. Flexible and comfortable footwear and medical gadgets also make use of it. Roofing, car seals, HVAC systems, and electrical insulation are just a few of the many uses for EPDM due to its high resilience to chemicals and weather. It is perfect for long-term outdoor usage due to its resistance to extreme environmental conditions.[8]

Based on the task at hand, either natural rubber or EPDM may provide distinct benefits. When it comes to settings that need durability, resistance to weather, and chemical stability, EPDM is the material of choice, but natural rubber is better suited for areas that require high tensile strength, abrasion resistance, and flexibility. The choice between the two materials is based on the needs of the application, guaranteeing long-term performance in a variety of commercial and industrial settings.

II. Review of Literature

Nassar, Amira et al., (2021)[9] This paper traces the history of EPDM rubber and how it has evolved to include shape memory alloy. The Cu-Al-Zn alloy was mixed with EPDM using a 2-roll mill method, and then the coupling agent 3-(Trimethoxysilyl) propyl methacrylate (TMSPM) was added. A variety of smart material engineering techniques may find use for the Cu-alloy due to its superelasticity behavior. There was an investigation on the mechanical, rheological, magnetic, and microstructure of Cu, Al, and Zn composites with EPDM. The results from the rheometer demonstrated that the use of Cu-Al-Zn as a filler enhanced the curing process. The curing time of the Cu-Al-Zn and EPDM composites was much shorter than that of the Cu-alloy-free control sample. Researchers found that increasing the Cu-alloy loading in EPDM composites improved mechanical properties, namely elongation at break. Composites using Cu-based alloy fillers exhibited superior magnetization compared to EPDM rubber and Cu-Al-Zn/EPDM composites without a coupling agent.

Nasruddin, Nasruddin et al., (2019) [10] Vulcanized solid tyres for forklifts, made with a mixture of natural and synthetic rubber in the optimal ratio of formula to process temperature, have been developed by engineers to fulfill the demands of commercial solid tire forklifts. The constant parameters in the process are time, temperature, and various materials such as natural and synthetic rubber, carbon black, silica, calcium carbonate, and coal fly ash. The results of the mechanical property tests conducted on forklift solid tires using Formula C were as follows: The specific gravity, hardness, tensile strength, tear strength, and abrasion resistance of the material are as follows: 1.195 g/cm³, 78 Shore A, 17.3 Mpa, 55.2 kN/m, and 160.8 mm, respectively. When tested for ozone resistance at 50 pphm, 20% strain, 24 hours, and 40°C, there are no cracks, and the modulus at 300% is 6.6%.

Indrajati, Ihda et al., (2019) [11] The relaxation behavior of NR composites, measured by their recovery after tension and compression sets, was successfully studied. We examined the behavior of recovery percentage with respect to physical and chemical crosslink densities. Several sulfur crosslinking agents and the filler carbon black N-330 were used to achieve this goal. N-330 loadings may be 30, 35, 40, or 45 phr with a baseline of 2 phr sulfur. Also used as a starting point are N-330 sulfur loadings of 30, 40, and 60 ppm. Strains of 25, 50, and 100% were applied during a continuous elongation in order to establish the tension. At 100°C, the trials continued for 72 hours. Keeping the deflection constant at 25% of the initial thickness, the compression set was carried out for 72 hours at room temperature and 100°C. The findings showed that, instead of crosslink densities, strain level was the primary element influencing tension set. Lower strain levels resulted in a higher recovery percentage. While the filler increment caused a considerable increase, sulfur had the reverse impact on the compression set. Compression set was higher at higher temperatures because to the presence of both physical and oxidative thermal degradation.

Wang, He et al., (2016) [12] Curing kinetics and mechanical characteristics of peroxide-cured EPDM compounds were investigated in this work, along with the impacts of three co-agents: triallyl isocyanurate (TAIC), trimethylol propane trimethacrylate (TMPTMA), and high vinyl poly(butadiene) (HVPBd). The results showed that the EPDM vulcanizates' hardness and modulus were improved, and that the samples' cure extent was increased, with the addition of each co-agent. In particular, the combination containing TAIC showed the highest level of healing. However, scorch safety was diminished with the addition of TMPTMA, especially at temperatures below 165°C. We found that the Deng-Isayev, first-order, and Hsich models were more in accord with experimental data than the Kamal-Sourour model when we used cure data from a moving die rheometer to calculate the cure kinetics of the EPDM compounds. At higher temperatures, TMPTMA and TAIC significantly accelerated the curing reaction rate, but HVPBd exhibited little change. In addition, the Deng-Isayev model produced considerably higher values for the apparent activation energies of all EPDM compounds when compared with the other three kinetic equations. However, adding all three co-agents lowered the activation energy of the curing process; the EPDM compound with TAIC had the lowest activation energy.

Fathurrohman, M.Irfan et al., (2015) [13] The vulcanization kinetics of EPDM rubber thermal insulation were investigated using a rheometer under isothermal circumstances and at different temperatures. Use of Rheometry allowed for the prediction of curing times for

EPDM thermal insulation. Curing curves for EPDM thermal insulation were found to be marching, and the appropriate curing time decreased with increasing temperature. The experimental results and the kinetic parameters computed using the autocatalytic model agreed rather well, indicating that the model was suitable for explaining the cure kinetics. The activation energy is determined to be 46.3661 kJ mol-1 according to the autocatalytic model. After collecting kinetic parameters, the autocatalytic model used the association between conversion degree, cure temperature, and cure time to predict the cure time. Cure time projections provide insight into the actual curing properties of EPDM thermal insulation. While all vulcanization temperatures (except 70 °C) resulted in the same hardness, tensile strength, and modulus of EPDM thermal insulation at 300%, elongation at breaking point decreased with increasing vulcanization temperature.

Hayeemasae, Nabil et al., (2013) [14] Natural rubber with virgin ethylene-propylene-diene-monomer (NR/EPDM) and NR/R-EPDM (natural rubber with recycled ethylene-propylene-diene-monomer) were both mixed. A steady 30 ppm of carbon black was also a component of it. The compounding, mechanical, and morphological properties of NR/R-EPDM and carbon-black-filled NR/EPDM blends were studied with different blend ratios (90/10, 80/20, 70/30, 60/40, and 50/50 (phr/phr)). As the weight ratio of EPDM or R-EPDM increased, the results showed that carbon-black-filled NR/EPDM and NR/R-EPDM blends had lower tensile strength and elongation at break. The scorch time (ts2), cure time (tc90), minimum torque (S′ML), maximum torque (S′MH), and torque difference (S′MH−ML) of the carbon-black-filled NR/EPDM or NR/R-EPDM blends rose as the weight ratio of virgin EPDM or R-EPDM in the blend increased. Scanning electron micrographs (SEMs) revealed matrix tearing lines and very rough surfaces in mixtures with low virgin EPDM or R-EPDM weight ratios. Even after 30 phr, the fracture path was reduced when the fraction of virgin EPDM or R-EPDM in the blends was increased. Because the crack channel is lessened, the barrier to fracture propagation may be lowered, and the tensile strength may be weak.

Ahmed, Khalil et al., (2012) [15] In this inquiry, researchers attempted to modify marble sludge (MS) by packing Ethylene-propylenediene monomer (EPDM) with chloroprene rubber (CR). Following compounding in a two-roll mill, vulcanization was carried out at 155˚C. The enhanced MS filed EPDM/CR mix was characterized by conducting research on the mechanical and swelling properties of blends, the effect of blend ratio on cure characteristics, and so on. The physical and elastomeric properties of cured MS-filled EPDM/CR mixes in aromatic, aliphatic, and chlorinated solvents were also investigated in relation to thermal aging. There was an initial increase and a little decrease in the blend's minimum and maximum torque after increasing the CR percentage in MS filled EPDM/CR mixtures. Increasing the CR content of the MS-filled EPDM compound enhanced the hardness, tensile strength, rip strength, cure rate index, and scorch time. Contrarily, reductions were recorded for elongation at break, robustness, abrasion loss, mole % absorption, swelling index, and percentage of soluble fraction.

III. Material And Methods

The following materials are utilized: NR-20 natural rubber, EPDM AT-903 ethylene propylene diene monomer, ZnO, stearic acid, CB, kaolin, $CaCO_3$, paraffin wax, paraffinic oil, N-Isopropyl-N'-phenyl-p-phenylenediamine, TMQ, CBS-80 additive rubber, tetramethyl thiuram disulfide and sulfur.

Rubber Compounding

Table 1 shows the formulation for each treatment, which includes natural rubber (NR) and ethylene propylene diene monomer (EPDM). The initial step was to masticate the NR for 5 minutes in an open roll mill Type SK-230. The addition of EPDM was delayed for 2 minutes after NR had become plastic. The activator Zn and co-activator stearic acid were added to the NR and EPDM composites at the same time until everything was mixed well, which took around 2 minutes. After that, for the next four minutes, the filler materials (carbon black, kaolin, and CaCO3), paraffin wax, and paraffin oil were added in that order. After 2 minutes, mix in the antioxidants (IPPD and TMQ) until everything is well combined. After two minutes of mixing, the accelerators DPG, CBS, and TMTD were introduced. The last step was to add sulfur, a vulcanizing agent, after the NR matrix and EPDM rubber had been combined well (3 minutes). The whole process of creating the rubber compound takes exactly twenty minutes. Over 8 minutes at 135 °C, the chemical was vulcanized.

Table 1: The ratio of tube collar vulcanizing material

Materials		**Formula**		
	TC-001*	**TC-002***	**TC-003***	**TC-004***
NR	70	80	90	100
EPDM	30	20	10	0
ZnO	5.5	5.5	5.5	5.5
Stearic acid	2.5	2.5	2.5	2.5
CB	87	87	87	87
Kaolin	18	18	18	18
$CaCO_3$	52	52	52	52
Paraffin wax	1.25	1.25	1.25	1.25
Paraffinic oil	1.5	1.5	1.5	1.5
IPPD	1.2	1.2	1.2	1.2
TMQ	1.3	1.3	1.3	1.3
DPG	1.2	1.2	1.2	1.2
CBS	1	1	1	1

TMTD	1.2	1.2	1.2	1.2
Sulfur	7.25	7.25	7.25	7.25

*phr = part per hundred of rubber

Test method

Compression set, 25% defl, 70 °C, 22 h (ASTM D.395-16e1), specific gravity (ASTM D.297-15), tensile strength (ASTM D.412-16) both before and after age, and samples were stretched at 20% strain and maintained at 38 °C for 24 hours prior to exposure to ozone at a concentration of 25 pphm (D.1149-16).

IV. Results And Discussion

Cure Characteristics Composites Compounds of NR with EPDM

The compounds derived from NR composites with EPDM and their maturation properties are shown in Table 2. It was clear from the test findings that the curing properties of the composite NR and EPDM compounds were different from one another. The bonds that are created in the composite matrix of each treatment, according to the ratio of components, are the possible source of the discrepancies. The scorch time (ts2), cure time (t_{90}), maximum torque (Smax), and delta torque (S) are the parameters that define the compound's curing properties. (S_{max} - S_{min}).

Table 2: Cure characteristics of composite NR and EPDM compounds

Curing Characteristic Rheometer 150^{0}C	**Formula**			
	TC-01	**TC-02**	**TC-03**	**TC-04**
S* Min, kg-cm	59.17	135.56	68.13	68.31
S* Maximum, kg-cm	63.60	145.26	70.86	70.92
Δs (Kg/cm)	4.43	9.70	2.73	2.31
Opt cure time (t90) min; sec	4.04	4.59	3.50	3.44
Scorch time (ts2), min; sec	0.40	0.02	0.06	0.06

Physical Properties

- **Specific gravity**

The density of the materials used to make the composite matrix for the tube collar is determined by measuring their specific gravities. The specific gravity of the rubber vulcanizate for the tube collar is affected by the ratio of materials used. The particular gravity test results for all four formulations are shown in table 3.

Table 3: Effect of NR and EPDM ratios on specific gravity

Formula	Specific Gravity (g/cm³)
TC-01	1.35
TC-02	1.55
TC-03	1.38
TC-04	1.40

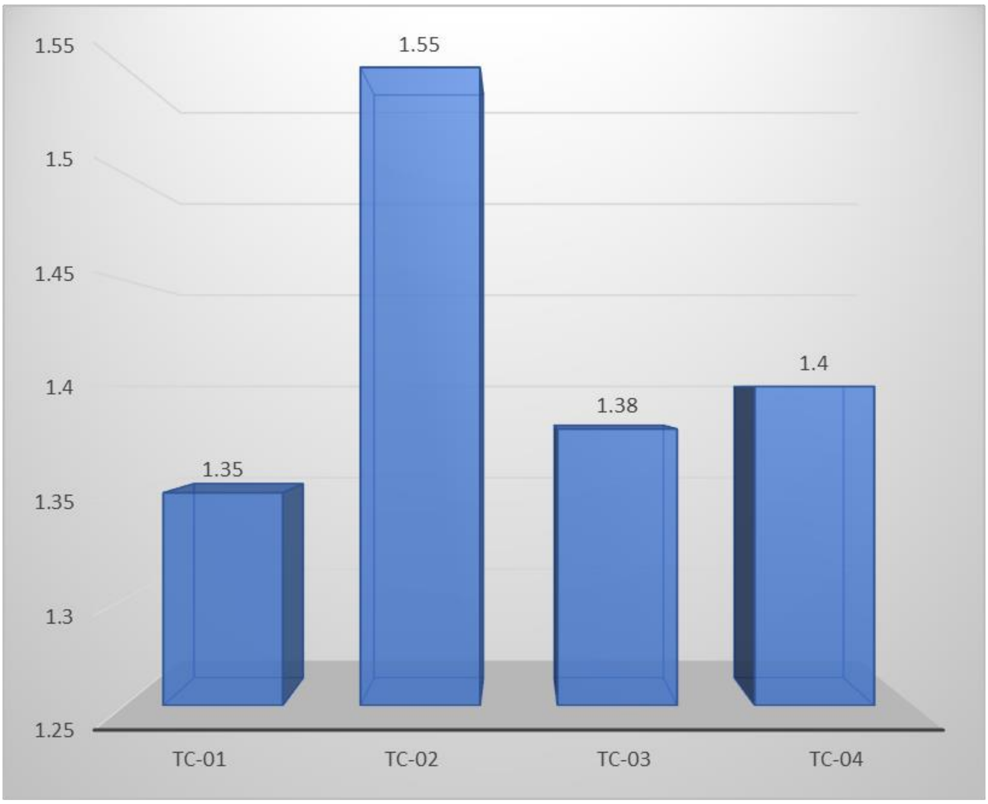

Figure 1: Effect of NR and EPDM ratios on specific gravity

It is possible that the greater EPDM content or more compact molecular structure contribute to TC-02's denser composition, since it displays the greatest specific gravity (1.55 g/cm³) among the formulations. The lowest specific gravity (1.35 g/cm³) was seen in TC-01, suggesting a lighter material. This might be due to a larger percentage of NR or a lower filler content. Both TC-03 (1.38 g/cm³) and TC-04 (1.40 g/cm³) have specific gravities that lie in the middle, indicating that the NR and EPDM components are somewhat balanced. The material composition impacts density, which in turn influences mechanical qualities, durability, and application acceptability in various industrial purposes; this is shown by the diversity in specific gravity throughout the formulations.

- **Tensile strength**

When the molecules that make up the vulcanizate are tugged in opposing directions, the strong bonds between them are described by the tensile strength. The vulcanization process forms cross-links of polysulfide and monosulfide, which contribute to the change in tensile strength values between the pre- and post-aging periods. The increase in tensile strength is a result of the increased number of cross-links that happen during vulcanization. The vulcanizate is also not very stretchy because of the interactions between the rubber, additives, and fillers. Table 4 shows that out of the four samples tested for tensile strength, the TC-03 formula had the highest value.

The tensile strength of TC-01 remained constant (10.01 MPa) both before and after ageing, however the values for TC-02, TC-03, and TC-04 were greater after ageing.

The cross-linking reduced after getting thermal heat after aging, which proves that the two variables are inversely proportional. It has been shown in several studies that the tensile strength value does not always decrease with age.

Table 4: Effect of NR and EPDM Ratios on Tensile Strength Before and After Ageing

Formula	Before Ageing (MPa)	After Ageing (MPa)
TC-01	10.01	10.01
TC-02	6.5	9.5
TC-03	10.5	16.5
TC-04	7.5	12.0

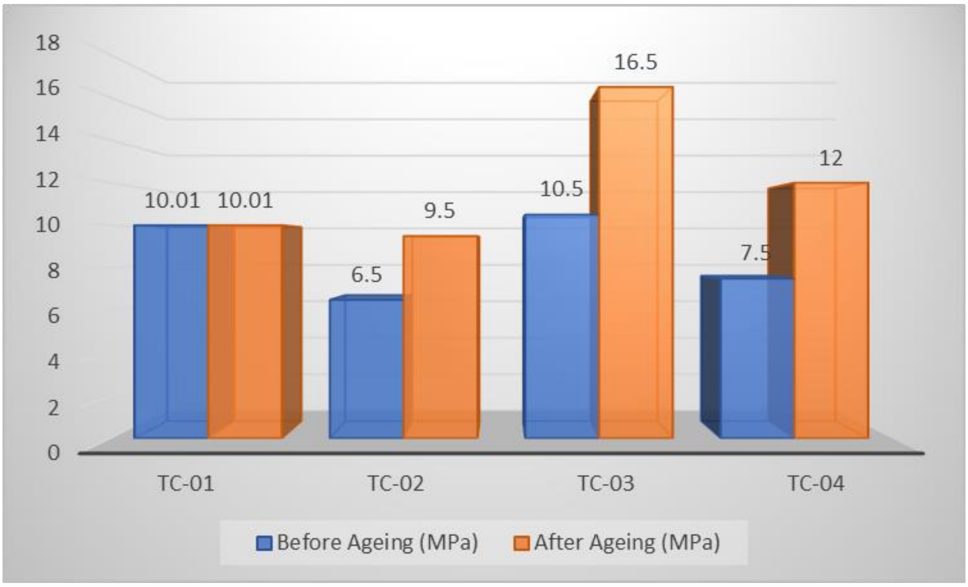

Figure 2: Effect of NR and EPDM ratios on tensile strength

Antioxidants may make NR and EPDM composites more resistant to oxidants as they age. Furthermore, EPDM might enhance mechanical qualities with age since it is a highly polarized rubber on NR. The greater polarity of NR and EPDM composites makes them age-resistant. The amount of force that may be applied to the patient stick depends on the tube's tensile strength at the collar. A material's rip strength decreases as its cross-linking density decreases. How strong the tube is to endure the strain is dependent on how easily it tears at the collar.

- **Compression set**

The tube collar's flexibility under stress and its ability to recover to its former shape are tested using a compression set. There is a noticeable difference in the characteristics of tube collars manufactured from plastic and those constructed from rubber composite materials, namely NR and EPDM. While pressure causes rubber tube collars to recover to their original shape, the lack of flexibility in plastic tube collars makes them vulnerable to physical damage under load.

Chemical oxidative thermal reactions and stress may both cause physical harm. The results of the compression set test for the tube collars of four samples of rubber vulcanizate are shown in Table 5. The highest value, 69.56%, was achieved at TC-02. The compression set sample test results shown that TC-01 (60.18%) is less than TC-02 but more than TC-03 (40.27%) and TC-04 (50.59%).

Table 5: Effect of NR and EPDM Ratios on Compression Set (%)

Formula	Compression Set (%)
TC-01	60.18
TC-02	69.26
TC-03	49.27
TC-04	50.59

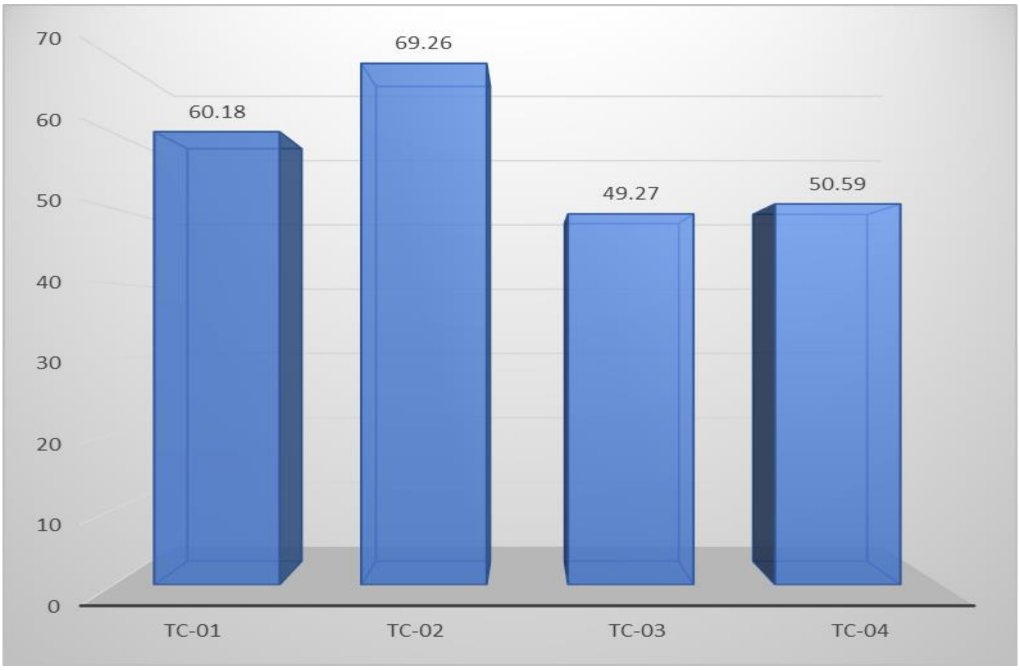

Figure 3: Effect of NR and EPDM ratio on the compression set

V. Conclusion

Important parameters for performance and longevity, such as specific gravity, tensile strength, and compression set, are shown to be substantially affected by material composition. TC-03 showed outstanding stress resistance after age with a tensile strength of 16.5 MPa, while TC-02 was denser but less elastic with a specific gravity of 1.55 g/cm³ and a compression set of 60.26%. These differences highlight the significance of finding the sweet spot between NR and EPDM in terms of strength, flexibility, and resistance to aging. This research is helpful because it sheds light on how to improve rubber compositions for uses in industry and medicine that need high mechanical performance and durability.

References: -

[1]. E. B. D. da Rocha, F. N. Linhares, C. F. S. Gabriel, A. M. F. de Sousa, and C. R. G. Furtado, "Stress relaxation of nitrile rubber composites filled with a hybrid metakaolin/carbon black filler under tensile and compressive forces," Applied Clay Science, vol. 151, pp. 181–188, Jan. 2018.

[2]. H. Yangthong, S. Pichaiyut, S. Jumrat, S. Wisunthorn, and C. Nakason, "Novel natural rubber composites with geopolymer filler," Advances in Polymer Technology, vol. 37, no. 1, pp. 2651–2662, 2018.

[3]. R. A. Rosszainily et al., "Effect of carbon black fillers on tensile stress of unvulcanized natural rubber compound," Journal of Mechanical Engineering Science, vol. 10, no. 2, pp. 2043–2052, 2016.

[4]. L. Shen, L. Xia, T. Han, H. Wu, and S. Guo, "Improvement of hardness and compression set properties of EPDM seals with alternating multilayered structure for PEM fuel cells," International Journal of Hydrogen Energy, vol. 41, no. 48, pp. 23164–23172, 2016.

[5]. M. Rebouah and G. Chagnon, "Permanent set and stress-softening constitutive equation applied to rubber-like materials and soft tissues," Acta Mechanica, vol. 225, no. 6, pp. 1685–1698, 2014.

[6]. Y. Lu, J. Zhang, P. Chang, Y. Quan, and Q. Chen, "Effect of filler on the compression set, compression stress-strain behavior, and mechanical properties of polysulfide sealants," Journal of Applied Polymer Science, vol. 120, no. 4, pp. 2001–2007, May 2011.

[7]. M. Abu-Abdeen, "Single and double-step stress relaxation and constitutive modeling of viscoelastic behavior of swelled and un-swelled natural rubber loaded with carbon black," Materials & Design, vol. 31, no. 4, pp. 2078–2084, Apr. 2010.

[8]. A. Maiti, R. H. Gee, T. Weisgraber, S. Chinn, and R. S. Maxwell, "Constitutive modeling of radiation effects on the permanent set in a silicone elastomer," Polymer Degradation and Stability, vol. 93, no. 12, pp. 2226–2229, 2008.

[9]. A. Nassar, D. Mahmoud, A. Moustafa, W. Mohamed, and S. El-Sabbagh, "Investigation of the structure, magnetic, rheological and mechanical properties of EPDM rubber/Cu-Al-Zn alloy composites," Egyptian Journal of Chemistry, vol. 64, no. 12, pp. 7377–7391, 2021.

[10]. N. Nasruddin and A. Bondan, "Natural rubber composites for solid tyre used for forklift tensile properties and morphological characteristics," Journal of Physics: Conference Series, vol. 1282, no. 1, pp. 1–3, 2019.

[11]. Indrajati and I. Setyorini, "Relaxation Behavior of Natural Rubber Composites Through Recovery Measurement after Tension and Compression Set," IOP Conference Series: Materials Science and Engineering, vol. 553, no. 1, pp. 1–10, 2019.

[12]. H. Wang, Y. Ding, and S. Zhao, "Effects of Co-Agents on the Properties of Peroxide-Cured Ethylene-Propylene Diene Rubber (EPDM)," Journal of Macromolecular Science, Part B, vol. 55, no. 5, pp. 433–444, 2016.

[13]. M. I. Fathurrohman, D. Maspanger, and S. Sutrisno, "Vulcanization Kinetics and Mechanical Properties of Ethylene Propylene Diene Monomer Thermal Insulation," Bulletin of Chemical Reaction Engineering & Catalysis, vol. 10, no. 2, pp. 1–4, 2015.

[14]. N. Hayeemasae and A. Azura, "Compounding, mechanical and morphological properties of carbon-black-filled natural rubber/recycled ethylene-propylene-diene-monomer (NR/R-EPDM) blends," Polymer Testing, vol. 32, no. 2, pp. 385–393, 2013.

[15]. Ahmed, S. Nizami, N. Raza, and K. Shirin, "Cure Characteristics, Mechanical and Swelling Properties of Marble Sludge Filled EPDM Modified Chloroprene Rubber Blends," Advances in Materials Physics and Chemistry, vol. 2, no. 2, pp. 90–97, 2012.