Effect of Manufacturing Process Parameters on the Tear Strength and Compression Set of Polyvinyl-Nitrile Rubber for Sealing Applications

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Abstract

Rubber has become one of the most widely employed polymers worldwide despite its mix of unique properties, particularly great compression and tearing strength coupled with remarkable strategic flexibility, that made it a vital and indispensable material for the creation of larger tires. Rubber is the seal material used in machine elements the most frequently. A catastrophic accident could occur if the rubber seal in structures that seal fails. Sealants inhibit the passage of hydraulic fluid while removing scratches caused by the piston's immediate communication with the inside surfaces of the engine cylinder. It is crucial to propose higher requirements for rubber's constancy owing to the demanding workplace and the inconvenience of changing it. Throughout the period of its existence, rubber can grow less reliable due to a variety of circumstances, such as load changes, external conditions, and heat treatment. Heat treatment of polyvinyl rubber has been employed in the present investigation. Four distinct factors, including curing period, curing temperature, post-curing temperature, and post-curing duration, were varied during the heat treatment. Specimens have been heat-treated depending on such variables. The universal testing machine, tear testing machine, and rheometer has been employed to examine the compression properties, tear behavior, and rheometric qualities. Results showed that the compression strength, tear strength, and rheometric parameters are significantly impacted by the heat treatment. The samples that were cured at 150°C had better compression set properties as compared to samples cured at 170°C. It can be observed from tear results that the tear strength for both specimens was 18 N/mm. The outcomes of the rheology test demonstrated the compound's favorable vulcanization capabilities. The rubber compound has plateaued after reaching its maximum torque. This shows that it has grown as strong as it can be and is not weakening as it cures.

Keywords: Polyvinyl rubber; Heat treatment; Tear strength, Compression behavior; Rheological analysis: Curing parameters

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1. Introduction

Since concrete cannot be constantly injected in conserving water as well as hydro-power productions, concrete structures, settling joints, and deflection joints are required to adjust to founding deflection and differences in temperature deflections. Since it's the most frequently utilized water-stop substance, rubber water-stop can actually prevent leaking and surface runoff of constructing joints while also acting as a suspension system as well as a cushion, making it extensively in use in productions. Rubber water-stop is frequently exposed to different climates in uses, such as oxygen, ozone, light, as well as temperature, causing it to change in both composition and structure [1-6]. Natural rubber, on the other hand, has a significant environmental benefit over fossil-dependent polymeric materials. To begin with, natural rubber is obtained from rubber trees, whereas fossil-dependent polymeric materials are deduced from gasoline by-products, implying that natural rubber is infinite, whereas fossil-dependent polymeric materials are finite. In the meantime, fossil-dependent polymeric materials probably burn as well as emit harmful emissions and pollutants into the atmosphere. Second, in terms of digestibility as well as reprocessing, fossil-dependent polymeric materials operate worse even than natural rubbers. Because fossil-dependent polymeric materials are hard to decompose, most of their product lines are thrown away and end up in the ocean. This pollutes the marine ecosystem and ends up killing a huge number of marine species, but natural rubber goods can be reprocessed, and several nations have also enacted regulations to that effect [7-9].

A seal can be defined as a device or a piece of material that closes an opening tightly so that air, liquid, or other substances cannot get in or out of that system. Seals are an integral part of almost all machines/engines and hence find wide applications in industries. Most of the process equipment or machines, or engines deal with some type of fluid, which makes sealing inevitable. There are various methods of sealing a system, and hence there are a wide variety of seals available and designed for specific applications.

Ethylene Acrylate-Butadiene Rubber (PVC-NBR), Carboxylated Nitrile (XNBR), Ethylene Propylene Rubber (EPR), Ethylene Propylene-Diene Rubber (EPDM), Butyl Rubber (IIR), Choloropropene Rubber (CR), Fluorocarbon (FKM), etc. are materials commonly used to make elastomer seals. The present study encompasses the experimental investigation of the effect of process parameters on some of the critical properties of a few widely used industrial seals. The specific objectives and methodology to be followed to realize the objectives and possible outcomes have been discussed in the subsequent headings.

A review of the literature was completed addressing the utilization of various seal kinds in a variety of industries. A summary of a few of the most significant and relevant scientific papers may be found as follows. Deng et al. [10] investigated the impacts of various aging temperatures and periods on the characteristics of various kinds of rubbers. The findings revealed that as the aging temperature and duration continued to increase, so did the rubber's microhardness and mechanical strength. Bo et al. [11] investigated the shifts in the mechanical characteristics of elastomers during and following aging, as well as the extent of aging with aging temperature and duration in a hot oxidative environment. The findings revealed that as the aging period, as well as temperature, increased, so did the ductility and rupture strain of elastomers, with such a slight rise in temperature resulting in a substantial reduction in mechanical characteristics. Beatty et al. [12] investigated the effect of time and pressure on elastomers in cold environments. The findings revealed that the microhardness of rubber substance at lower temperatures grew with increasing period and force, and it was suggested that crystallization was one of the causes of the rise in rubber microhardness.

The visualization and characterization of brush sealing showed common sites with various kinds of flow types. Following the identification of the axial pressure profiles under several inlet pressure circumstances, pressured mappings were created [13]. Studies have been done to determine how the brush's position, shape, and microstructure impacted how well the sealing surface interacted, how much fluid leakage there was, and how much pressure was lost consequently [14]. To observe and characterize the complicated liquid motion in reproduced solitary as well as double sealings, a technique was formed. The flow characteristics and corresponding fluid velocity inside the brushes were non-intrusively discovered and graphically reconstructed [15]. They investigated the fluid velocities and flow rates inside a collection of brushes using the full-flow field processes to maintain. To determine the factors affecting variations in seal leaking, these have been visually recreated [16]. The leak behavior of a brushed sealing with gas fluids was already investigated in steady and reduced rotor speed conditions. The principle of the given situation has been applied to gather data on Carbon dioxide and air. Contrary to the findings for air and Carbon monoxide, those for helium showed a clear curve [17]. A non-contacting or clear sealing architecture for air turbine openers was already developed, consisting of numerous whirling blowers and oil-air separators. A forecast of dependability increases due to the creation and validation of a cleared sealing to substitute a contacting driveshaft sealing is offered [18].

It provided instructions on how to build, examine, and assess non-contacting gas face sealings for use in aerospace applications. In order to enhance security and reduce leaking variation, non-contacting seal technology is being employed in lieu of contact-facing gaskets in airplane seal systems [19]. A non-dimensional similarity between the flow characteristics of modeling sealings and motor sealings has been discovered. The homogenous asymmetrical resistivity of the brushed sealing pack offered suitable flow rate characteristics. However, the modeling misrepresented the characteristics of force dispersion [20]. Computation and evaluation of brush elastic deformation, bending loads, and bristles or rotors contact stresses have been done for brush sealings used in jet engines. Due to radial fluid motion, such stresses are generated at the contact between the fiber and rotor surface. Associations for the complementary non-dimensional loads were developed. The employment of the non-linear beams concept is justified by the evaluation of brush pressures and deflections in the scope of brush seal mechanical examination. Measurements were made of the high flexural stresses' position and magnitude [21].

The advantages of non-metallic brushing seals for lubricated seal applications were discussed. Non-metallic brush seals have been discovered to be more efficient in preventing leaks than metal brush sealings as well as labyrinth seals. The benefits of producing the exact same thing were highlighted [22]. A technique for porous load calculations was already developed. The results accurately depicted the brush seals as a porous material with a thin approach [23]. Using a unique method and programming skills, the behavior of the bristles in brush sealings in three-dimensional space was already anticipated. The results showed that bends behaved as expected in live brush seals [24]. The creation of sealing with a pattern-like brush seal, however, using small slices instead of the cables present in conventional brush seals, has been proposed. It was concluded that this sealing technique is practical for application [25]. A testing approach has been proposed to determine the stiffness and damping characteristics of rubber O-rings subjected to small-amplitude rotational movement. This could be utilized to investigate several significant factors that affect the dynamic properties of O-rings [26]. To determine how variable O-ring properties were, many investigators subjected them to expedited aging tests. The compressing Set was handled as a single variable by certain investigators. It must have been found that the NBR O-ring degrades much more quietly in an electromechanical relay actuator compared to when exposed only to air. Due to a paucity of failure data, estimating the O-rings' lifespan became difficult. As a result, many investigators have used the expedited disintegration test to calculate the anticipated life span of the O-rings [27, 28]. Rapid thermal aging tests on nitrile rubber O-rings have been conducted [29, 30] to better understand how working circumstances affect seal quality. The use of an alternate material for the rectangular groove-encased fluorocarbon seal in nuclear fuel delivery flasks was investigated in a study. While comparing the current seal materials to EPDM sealings, the permeability to liquid, hydrogen, calcium, or magnesium salt solution, as well as radiation resistance, were taken into consideration. The findings demonstrated that the mechanical properties, radiation resistance, and moisture resistance of the EPDM polymers were good. It was found that gas and water had higher penetration rates [31]. The effect of aging on the ability of elastomeric O-rings to seal was studied, and it was discovered that the leakage rate decreased with aging. The fact that component functions like static leakage rate does not always correlate with other mechanical properties, however, was shown by a significant decline in other material properties [32]. Investigations [33, 34] have shown that rubber O-ring sealings help avoid hydraulic fluid leaks as well as scratches caused by direct contact between the piston and the cylinder block's inner wall. Extreme temperatures, quick rubbing motions, hostile environments for elastomeric materials, cylinder ports that seals must cross, and large shaft clearances are some of the issues that limit the use of O-rings [35]. O-ring sealings, an example of an elastomer sealing, are used extensively throughout many industry sectors for a variety of reasons, including their broad operational range, ease of maintenance, low risk of causing structural damage, compact design, high likelihood of reusability, gradual failure, low cost, etc. [36]. The breaking behavior of rubbers was examined using fracturing mechanics. It was found that there was a good correlation between the experiment and non-crystallizing rubbers. Natural rubbers that are strain crystallizing, however, cannot form crystals under these test circumstances [37].

Ductility at breakage and slip resilience has been the options selected for the rubber material used in shoe soles. The two optimization algorithms being used are backpropagation neural networks and particle swarm optimization. Mold temperature, mold pressure, and holding time were improved for increased elasticity as well as slide resilience. Experimental validation of data showed a 30-percentage reduction in the cost of quality [38, 39]. Two different calibrating techniques for tracking ozone concentration were compared. The worldwide rubber sector includes UV spectrophotometers, whereas the German rubber industry uses a wet chemical examination process. Different results would result from these two strategies. Rubber specimens were used to compare the results of ozone tests conducted in the actual world. There were debates about the implications of the differences in the ozone content estimations provided by the two calibrating approaches [40]. From the literature review, it was noted that the studies on compression and shear behavior of heat-treated polyvinyl rubber had not been paid much attention. Hence, the present study aims to investigate the effect of heat treatment on the compression and shear behavior of polyvinyl rubber.

2. Experimentation

2.1 Materials and processing

Fig. 1 depicts the process map to produce rubber seals. Before its single-unit molecules could be linked to form bigger, multi-unit molecules underneath the action of free-radical initiators, acrylonitrile (CH2=CHCN) and butadiene (CH2=CH-CH=CH2) must first be emulsified in water to produce NBR. Acrylonitrile makes up 15-50% of the final copolymer. When the rubber's acrylonitrile concentration increases, it becomes harder, more resistant to dilatation by hydrocarbon oil, and less porous to gases. Nevertheless, because polyacrylonitrile has a higher glass transition temperature, the rubber loses elasticity at fewer temperatures (that is, the temperatures beneath which the molecules are locked into a rigid, glassy state). The composition had the main essential ingredients in amounts of parts per 100 rubbers (PHR). Using small traces of Zinc Stearate, Zinc Oxide, Stearic Acid, and Sulfur as a coupling agent, NBR is 70, PVC is 30, and Dioctyl Phthalate (DOP) is 50. The curing and heat treatment procedures proved appropriate to be taken into consideration for this investigation because they required substantial energy and time inputs, according to what has been observed during the procedure and what was discussed with the technical staff. To comprehend the factors impacting the regression coefficients, a cause-and-effect diagram is built. The cause-and-effect network for the mechanical characteristics of the PVC-NBR created with the R software is shown in Fig 2. The investigation employed a 2^4-design with 3 replications to identify the optimum parameters that were impacting the mechanical characteristics of the O-rings. The Minitab simulation tool has been used to design the experimental running order. The factors considered carefully are shown in Table 1, together with their respective value ranges. Compressive strength, load at fracture, and ductility (or elongation) have been taken into consideration as the response factors. To make certain that the equipment was operating properly, trial tests have been performed. To make sure that everything went as planned, the procedure was closely watched. The settings were established with consideration for the experiment. The processing factors were considered when creating the standard order. The experiment's execution sequence was randomly chosen in order to reduce the impact of noise. The samples' compression and shear characteristics were then examined.

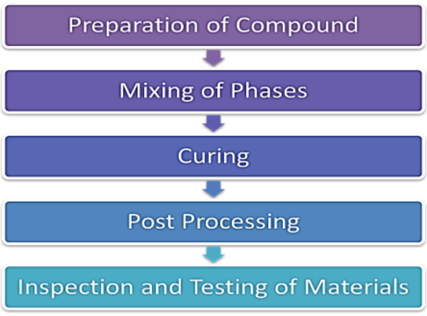

Figure 1: Process flow chart of elastomer seal manufacturing process

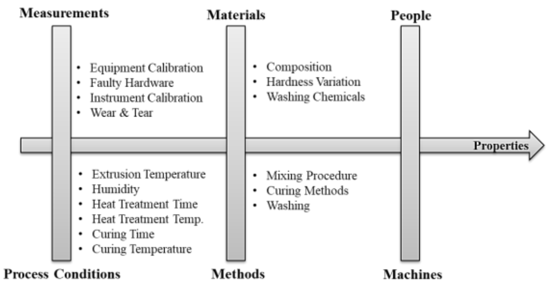

Figure 2: Cause-and-effect diagram for mechanical properties

Table 1: Process control parameters with level and range

Control factors	Low	High
Curing temperature (°C)	150	170
Curing time (min)	14	18
Post Curing temperature (°C)	50	100
Post Curing time (min)	60	120

2.2 Rheometric analysis

The rheometer's warmed cavity is filled with a compound at ambient temperature. The viscosity of the compound decreases as it warms, which is reflected in a reduced torque (resistance) on the rotor. The torque curve's lowest value, Moment Lowest (M_L), is represented in dNm. It is a measurement of an un-vulcanized compound's ductility at a specific temperature. The torque rises as the vulcanization process continues. Ts_2 is the interval between the start of the test and the point at which the torque value increases by 2 dNm above the M_L value. The compound's starting point for vulcanization is indicated by the Ts_2 value, which is expressed in time units.

The torque increases as we get closer to the final cross-linked compound. Depending on the cross-linking method employed, the slope of growth varies. The curve normalizes after a while. The torque curve's greatest value, MH, is represented in dNm (Moment Highest). Often, three scenarios are feasible. It is conceivable for certain compound types (NR, CR) to have the reverse effect and run the risk of over-vulcanizing the compound, which is reflected in the final products' insufficient hardness. It is possible, nevertheless, for the curve to keep rising, as is typical for EPDM compounds. The period between the test's beginning and when 90% of the M_H value is obtained is known as t_{C90}.

2.3 Compression Set

The tendency of rubber to regain its initial size following extended compression pressures at a specific temperature as well as bending is measured by compression set examination. The rubber term "compression set" refers to a rubber's loss of thickness after being stretched beneath a particular load, duration, and operating temperatures. It is typically measured as a percentage and evaluated in accordance with ASTM-D395 Procedure B. Once the rubber has been crushed for a particular amount of time, it loses its capacity to regain its initial size. The capacity of an elastomer sealant, gasket, or cushion padding to work throughout the period could be diminished by this lack of resilience (storage). A shock isolator pad's capacity to shield an unintentionally fallen item may be endangered because of the lasting harm that a gasket might acquire throughout aging. Outcomes from a material's compression set tests were represented by a percentage. The substance resists permanent deformation underneath a particular bending and thermal gradient better with a smaller proportion. Outcomes from compression set tests can be difficult to understand because they are computed differently depending on the measurement technique.

Most of the Compression Set examinations use Standard Test B from ASTM-D395. By using the fixture shown in Fig. 3, hard elastomeric samples 0.25-inch thickness by 0.52 inches in diameter are crushed to 0.177′ inches thick over a duration of 23 to 70 hours at a high temperature in an air-circulating furnace.

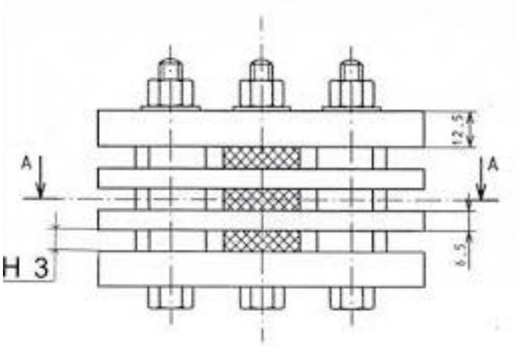

Figure 3. Typical fixture for determining compression set of elastomers

The percentage of bending which did not recur is represented by the Compressive Set. This indicates that the Compressive Set will be 40 percentage points when a specimen, such as a rubber disk, is examined for 70 hours @ 343 K, then left to cool for half an hour. The disc was deviated by 0.074 inches and recovered by 0.045 inches (back up to.221), meaning that 40 percent of the compression length has been lost. Less quality, less-cured, or improperly mixed rubberized sheets would display a compressive set of 45 percent or more. Good-grade hard material has a compression set of about 20 percent; usually, sheet rubber has a compressive set of around 30 percent. A standardized test sample, as depicted in Fig. 4, is weighed, and afterward reduced in thickness in some kind of jigs to a specific percentage. The jig is put into a hot oven for a predetermined amount of duration, retrieved, and allowed to recoup before being weighed again. A decompression set value is calculated through computation. Compressed sets can be represented in two different ways, as an expression of the amount compressed.

Compressive Set = $((t_0 - t_1) / (t_0 - t_s)) \times 100$ (I)

The expression of the overall thickness of the test sample.

Compressive Set = $(t_0 - t_1) / t_0 \times 100$ (II)

Where t_0 = original thickness, t_1 = thickness of sample after the recovery, and t_s = thickness of the spacer bar utilized. The percent set at point 1 above represents a percent of the compressive thickness, while the percent set at point 2 above represents a percent of the entire thickness of the test sample. For example;

A 20 mm sample is compressed by 50 percent

(20 mm – 15 mm) / (20mm – 10 mm) x 100 = 50 percent compression set.

(20 mm – 15 mm) / 20 mm x 100 = 25 percent compression set

Figure 4. Photograph of Compression Set Specimen

2.4 Tear Strength

The degree of resilience to fracture growth in elastomers is indicated by shear/tear strength. Being one of the crucial mechanical criteria for rubber compounds, tearing resilience is utilized to describe these items. St is the amount of force required to cause a substance to tear and for a fracture to spread outward till it breaks. The manner a force is exerted, and the material's architecture both affect the type of rip that results. Based on the way it is tugged, in which way, and whether the vulnerability develops from the center or the edges, a material can rip in a unique way. According to ASTM-D624: Standardized Test Procedure for shear strength of Traditional Vulcanized Rubber and Thermoset Epoxies, a shear strength examination has been conducted. Sliced samples have been produced from molded test sample sheets for shear investigation, as depicted in Fig. 5. During this time, the cutting surface of vulcanized rubber altered in a manner that could influence when ripping starts. Because of this, it is crucial to adhere to the conditioned pauses and use cutting dies, nicking tools, and knives. The test specimens have been thusly cleaned, conditioned, and tested for shear strength. After that, the test sample is carefully positioned in the test machine's gripping to ensure that it is stretched evenly across its length and that enough substance is gripped in the grip to reduce slipping, as shown in Fig. 6. The machine is started at a constant grip separating rate. The test component is put under pressure until it ruptures entirely. The strongest force is noted. The shear strength, S_s, in kN/m of thickness, is measured using the equation; S_s= W/t (Where: W = the maximum load, in N and t = the average thickness of each test sample, in mm).

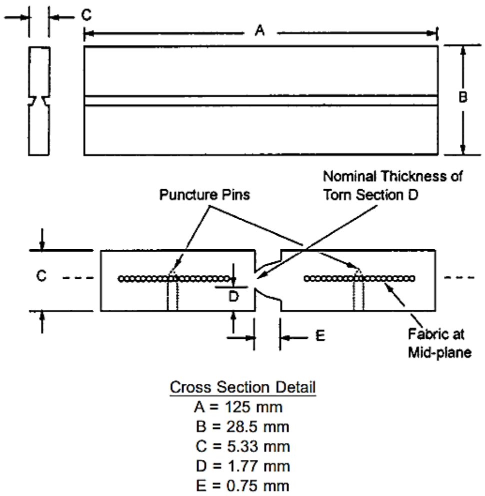

Figure 5. Schematic diagram of "Constrained Path" tear test piece

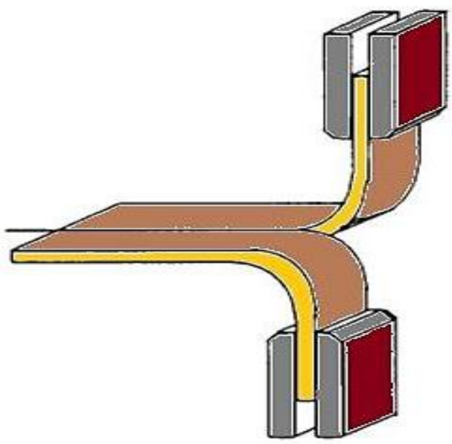

Figure 6. Positioning of Trouser Tear Test Specimen in machine

Results and discussion

3.1 Rheometric analysis

The impact of compound change on curing properties is assessed using a rheometer. It is a method for evaluating the rheological characteristics of material; rheology is the investigation of matter's flowing and plasticity and explains how load, deflection, as well as period, interact. The manufacturing regulation and chemical development method both benefit from the research conducted. Along with processing as well as curing qualities, the rubber compound's physical aspects can be evaluated. The rheometric characteristics were ascertained using the oscillating disc rheometer. An example of a rheometric curve is in Fig. 7. The rheometric curve serves the following functions (i) It displays the rubber compound's curing properties, (ii) It keeps track of the material's physical features and manufacturing traits, and (iii) The vulcanization and processing characteristics of the chemical are fingerprinted by the cure curve. The shear modulus (G, MPa) is given by;

$$G = V \times R \times T \quad (1)$$

Where V is cross-limiting density (Mol/mm^3), R is gas constant (J/Mol. K), and T is the thermodynamic temperature (K).

A rheometric examination of vinyl-nitrile rubber, which contains 30% PVC and 70% NBR, was performed. Tests were conducted in accordance with ASTM D-1646 Specifications. The outcomes demonstrated the compound's favorable vulcanization capabilities. The rubber compound has plateaued after reaching its maximum torque. This shows that it has grown as strong as it can be and is not weakening as it cures. After several tests with various formulas, the current combination was deemed suitable to move forward with additional property testing. This is so that it is clear from the curve depicted in Fig. 8 that the compound neither reverts nor increases in modulus as a result of over-curing. As a result, the process of creating the compound was optimal, and it can be used for additional research. Rheometric curves can be used to make observations about the processing features of the compound, the slope of rise during the curing phase, the curing qualities of the compound, the further shape of the curve, or the predicted physical attributes of the compound. By conducting additional testing with the right techniques, it is possible to ascertain the attributes such as tensile strength, hardness, compression set, tear strength, resistance to ozone, etc.

The mechanical and technological response of the final materials is significantly influenced by the rheological properties of modified building mixes. A section of the building products business that is rapidly expanding is the production of mortar using dried construction mixtures [41,42]. There are many different types of dry mix mortars, including dry mix materials and additives in a dry state. In the past fifty years, numerous raw materials for making dry construction combinations were researched, and manufacturing processes were created and put to use. Today, water-retaining chemicals, phthalates, water bug repellants, ingredients that enhance adhesion capabilities, etc., are utilized to create special plaster mixtures [43,44]. Re-dispersible polymeric powder is the most popular polymeric modifier for dry building mixtures. They are made by emulsified polymerizing or copolymerizing polymeric materials in the dispersion phase; after additional spraying as well as drying methodologies, they can produce a dispersion in water. The Re-dispersible polymeric powder is instantaneously as well as totally re-dispersed after being combined with water, as well as the disseminated particles come together to produce films that have a mechanical strength of almost 5 MPa. These polymeric films are strengthening the holes, microscopic spaces, and holes of the hard mixes, increasing their ductility, and ripping off the base adhesion. In order to strengthen the uniformity of the hard mortars, the adhesion strength, compressive as well as tensile strength during the bend, plasticity characteristic, water permeability, temperature resistance, etc., these could be utilized. Cellulose ethers are useful additions to improve the ability of dry construction mixes to retain water. A water-retaining ingredient raises the water infiltration of a standard cement mix from 75–80% to 9–98% in a thin coating. By interacting with other molecules, dissolving cellulose molecules create aqua compounds that securely keep the water. A large rise in viscosity is also brought on by the inclusion of cellulose, which also inhibits the settling of cement and filler particles. According to certain writers, the presence of cellulose boosts the viscosity of mortar solution as well as, based on how much is present, can either enhance or decrease the tensile stress as well as the viscosity of mortar. This base-level reduction in the hydrophobic interactions brought on by the cellulose bound onto cement grains has been reported in work. The adsorption ad-mixture causes bridge emulsification, which raises the tensile stress of cementitious materials. According to the research, a specific type of cellulose ad-mixture is specifically correlated to how much an independent ad-mixture affects the rheology of mortars. Whenever the viscosity of cellulose ad-mixtures has been continued to increase further, it did not have as much effect on the uniformity of the mortars. The most observable uniformity modification has been seen for hydroxy-propyl-methyl cellulose and hydroxy-ethyl-methyl cellulose-based ad-mixtures, wherein circumstance, the viscosity rose from roughly 6000 MPa-s to nearly 30,000 MPa-s. The different molecular weights and structural variances of the cellulose polymers utilized are what cause the variations reported in the literature. As a result, the type of additives as well as additional alloying elements in the mixtures, affects how these alloying elements work and how they affect the rheological qualities. Our research, which worried and concentrated on the effect of heat treatment on the compressive, tear, and rheological behavior of polyvinyl rubber, concerned and produced better results compared to earlier examined suspensions.

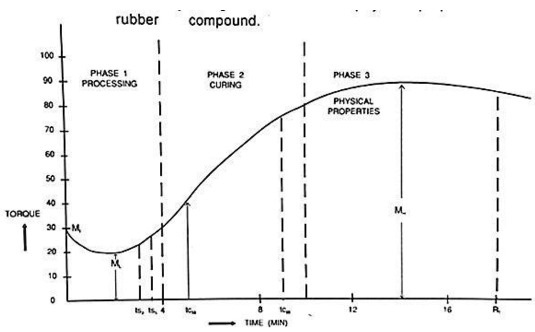

Figure 7. Typical Rheometric Curve

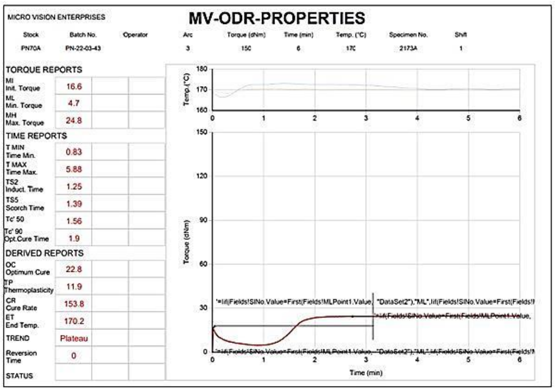

Figure 8. Rheometric curve for PN70 PVC Nitrile rubber

3.2 Compression Set analysis

The compression set has been evaluated in accordance with the method outlined in the previous section. The samples have been cured at temperatures of 150°C and 170°C. The experiment was carried out using the variables shown in Table 2. The compression set values were obtained, and the same is tabulated in Table 3. The samples that were cured at 150°C had better compression set properties as compared to samples cured at 170°C, as depicted in Fig. 6. Similar results were observed (Fig. 7) when the test was conducted at 23°C/ 72 hours / 25% strain. Hence, a curing temperature of 150°C gives a good result for the compression set.

Yang et al. [45] used cold stamping to create an O-type metal rubber sealer with a big ring-to-diameter proportion with a geographic network model with intertwined metallic wires as well as decent non-linear elastic mechanical characteristics. Nevertheless, irregular trying to lay, cord breakage, and/or fissures could invariably deteriorate the mechanical characteristics of the specimen during the winding process. Postprocessing is generally required to eliminate that kind of inadequacies in the specimen. Because heat treatment does have a larger influence on the mechanical characteristics of the test specimens, the influence of heat treatment on specimen performance has been examined using a compression set test. The force-displacement comparative chart illustrates multiple specimens' porosities undergoing the same load after heat treatment, as well as their corresponding specimens with no heat treatment process. The influence of the heat treatment process on the losing factors as well as energy dissipation of all specimens having varying permeability with the same load as estimated by equation (1) using computational source code, also was demonstrated. According to their findings, both the heat-treated and un-treated specimens showed comparable oscillation characteristic features. With the same displacement, heat-treated specimens could indeed endure greater loads than un-treated specimens; nevertheless, the former consumed significantly less energy than the second. The effects of the heat treatment process on the testing specimen are quantified. The losing factor, as well as energy discharge of the heat-treated specimen, were lower compared to the un-treated specimen for specimens with the same permeability. The losing factor varied between 0.18 and 0.56, as well as the energy dissipation varied between 0.34 and 0.79. The variability of both reduced as permeability increased. The heat-treated sample's energy dissipation had also been lowered. The losing factor reduced as permeability increased, indicating that the heat treatment used to have a significant impact on the specimen characteristics. The primary causes of this occurrence could be explained by the fact that higher temperature heat treatments reduce the localized stress density induced by plaiting as well as cold pressing of the metallic wires in the specimen as well as lessens the point of contact between the metallic wires, leading to a reduction in deflection rebellion and energy dissipation. As a result, the O-type metal rubber sealer can indeed be organized through an appropriate heat treatment process as well as specimen permeability modification.

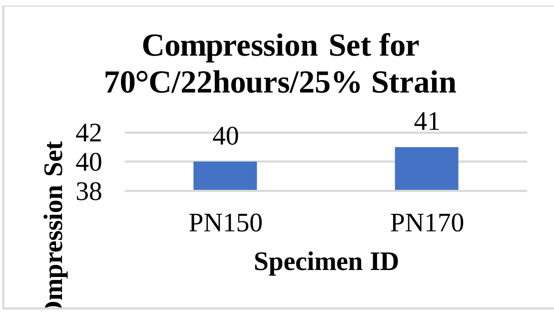

Figure 6. Compression Set for 70°C/22 Hours / 25% Strain Samples

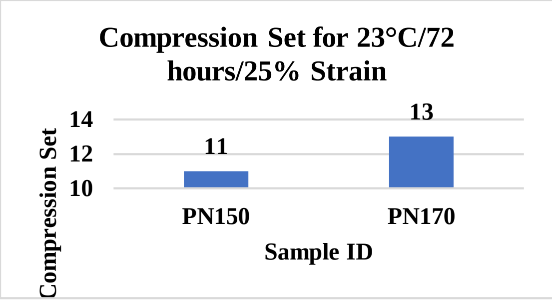

Figure 7. Compression Set for 23°C/72 Hours / 25% Strain Samples

Table 2. Compression Set Parameters

Temperature, °C	Duration, Hour	% Strain
70	22	25
23	72	25

Table 3. Compression Set values

Sample ID	Temperature, °C	Duration, Hour	% Strain	Median Compression Set in %
PN150	70	22	25	40
PN170	70	22	25	41
PN150	23	72	25	11
PN170	23	72	25	13

3.2 Tear Strength analysis

Tear Strength was measured as per ASTM D-624. Specimens were prepared as per the standard with curing temperatures of 150°C and 170°C. The test was conducted on four samples for each curing temperature, and the average value was determined. It can be observed from Table 4 that the tear strength for both specimens was 18 N/mm.

The relationship between the imprinted material's curing period and tear strength is quite significant. For patients as well as doctors, reduced setup durations are more practical; nevertheless, if the setup duration is insufficient, as well as the imprint material really hasn't fully polymerized prior to removal, the impression material would rip [16]. One hour following every material supposed setting time, as stated by the supplier, a tear strength investigation has been carried out in the current investigation. The tear strength of polyether is shown to be greater compared to poly-vinyl-siloxane or vinyl polyether silicone hybrid, despite the fact, there isn't a statistically substantial distinction between the 3 materials. In contrast to the findings of Lawson et al. [46], who claimed that added silicon materials had stronger tear strength over polyether substances, this is in accordance with the research conducted by Huettig et al. [47]. This can be because various characteristics and tear rates were used in the current investigation. The relationships between the imprint material and sulcus fluids might well be impacted by the relative degree of hydrophilicity or hydrophobicity of the various materials. These liquids' inclusion throughout polymerization may lead to flaws that serve as stress promoters, lowering the polymerized material's tearing strength [48]. Contrarily, compared to the other rubber impression materials, poly-vinyl-siloxanes bend at a much slower rate and rip at areas of less lasting deformity [49], as well as being less stiff than polyether while set. To change the working duration, changing substances, film thicknesses, and different temperatures might affect tearing strength [50].

In comparison to poly-vinyl-siloxane, the vinyl polyether silicone hybrid material demonstrated a significantly decreased tearing strength. More research is needed to determine if this comparatively reduced tearing strength can result in intraoral or detachment from casts tearing of impressed material. It is also important to note that the current research did not test the material's adherence to dental and body tissues or the existence of cavities, which are factors that have a significant impact on tearing strength [51].

Impression materials are polymeric materials having crimped portions which are completely versatile as well as uncoil to move around freely when loaded. A perfect rubber would show full elastic properties as well as restore to its pre-stressed shape after the load is removed. The extent to whereby this happens is a gauge of the material's elastic modulus [52]. The degree of persistent deformation that the substance experiences is significantly determined by the temperature, pace of applied stress, as well as the degree to which cross-linking occurs of the polymeric material chains. A compressive test instead of a tensile test has been used in the current investigation to examine the elastic properties. The substances investigated in this research all complied with ISO-4823, which calls for higher than the elastic modulus. A study's [53] findings revealed that poly-vinyl-siloxane had the overall average elastic properties, trailed by vinyl polyether silicone hybrid as well as polyether, albeit these variations could not be potentially beneficial. Elastic recovery for polyvinylsiloxane materials depends on the presence of base silica, copolymer filler, and chain extenders. The lowest visco-elastic materials, such as poly-vinyl-siloxanes, rebound from visco-elastic deformation the fastest. Polyvinyl-siloxanes, according to research, have enough elastic properties to enable an imprint to be formed only 6 minutes after being taken out of the mouth. According to Lu H et al. [54], polyether had a stronger elastic recovery than the newly added silicone materials. These findings are in direct opposition to their findings. This could be a result of the different material manufacturers, viscosity values, as well as research methods used in the current study. Vinyl-polyether silicone hybrid substance has been rated between polyether and poly-vinyl-siloxane; because it is a hybrid material having both polyethers as well as siloxane groups, polyether material provides fewer elastic properties than poly-siloxane materials, its elastic recovery falls between them. The current study outcomes are in line with the above-mentioned studied.

Table 4. Tear Strength Values

Sample ID	Median Value	Individual Values
PN150	18	18, 17, 17, 18
PN170	18	18, 18, 18. 18

4. Conclusion

By adjusting process parameters such as curing time, curing temperature, post-curing temperature, and post-curing time, the polyvinyl rubber was given various heat treatments in the current investigation. Rheometric analysis was carried out; later the properties such as compression set behavior and tear strength were investigated, and the following conclusions were extracted.

- Rheometric analysis results showed the compound to have good vulcanization properties. The maximum torque of the rubber compound has been reached. This demonstrates that it has reached its maximum strength and is not deteriorating while it heals. The current combination was found to be suitable to proceed forward with additional property testing after multiple tests with other formulations.
- The values for the compression set were acquired, and the results show that the samples that were cured at 150°C had superior compression set characteristics than the samples that were cured at 170°C. Similar outcomes were seen when the test was run for 72 hours at a 25% strain at 23°C. For the compression set, a curing temperature of 150°C, therefore, produces good results.
- According to ASTM-D624, tear properties were measured. In accordance with the specification, specimens were made using curing temperatures of 150°C and 170°C. At each curing temperature, four samples were tested, and the average value was calculated. The rip strength for both specimens was 18 N/mm.

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