OPTIMIZATION OF PROCESSING PARAMETERS USING TAGUCHI TECHNIQUE FOR MECHANICAL PROPERTIES OF DIFFERENT DAMPING MATERIALS

A project report submitted in partial fulfillment of the requirement for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

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SANGIVALASA, VISAKHAPATNAM (District) – 531162

2021

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CERTIFICATE

This is to certify that the Project Report entitled **"OPTIMIZATION OF PROCESSING PARAMETERS USING TAGUCHI TECHNIQUE FOR MECHANICAL PROPERTIES OF DIFFERENT DAMPING MATERIALS"** being submitted by GANDI UDAY SAI (317126520193), GOKADA MAHENDRA (318126520L52), PARRE RAMKUMAR (318126520L47), BELLANA VINAY (317126520185), SHAIK FAROOQ (317126520221) TIVIRISETTI VENKATA RAVEENDRA SAI KRISHNA (316126520055) in partial fulfillments for the award of degree of **BACHELOR OF TECHNOLOGY** in **MECHANICAL ENGINEERING**. It is the work of bona-fide, carried out under the guidance and supervision of **DR.M.PRASANTH KUMAR**, Assistant Professor, Department Of Mechanical Engineering, ANITS during the academic year of 2017-2021.

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ACKNOWLEDGEMENTS

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ABSTRACT

In this investigation, Taguchi technique is used to find optimum process parameters for mechanical properties of different damping materials like Natural rubber, Nitrile rubber and Neoprene rubber of 40, 50 and 60 shore A hardness. A L9 orthogonal array, signal-to-noise(S/N) ratio and analysis of variances (ANOVA) are applied with the help of Minitab.v.20.2.0.0 software to study the effect of processing parameters namely accelerator and carbon black content with consideration of mechanical properties like hardness, tensile strength and % elongation. The results obtained from the experiments are changed into signal-to-noise ratio (S/N) ratio and used to optimize. The ANOVA is performed to identify the importance of parameters.

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CHAPTER - I

INTRODUCTION

1.1 INTRODUCTION ABOUT DAMPING

Damping is the energy dissipation of a material or system under cyclic stress. Three main types of damping are present in any mechanical system:

- ➢ Internal damping
- ➢ Fluid damping
- ➢ Structural damping

1.1.1 Internal Damping

Internal damping is caused by microstructure defects-impurities, grain boundaries, thermo elastic effects, eddy-current effects in ferromagnetic materials, dislocation motion in metals and chain motion in polymers. Besides, there are two types of internal damping: viscoelastic damping and hysteretic damping.

1.1.2 Fluid Damping

When the material is immersed in a fluid and there is relative motion between the fluid and the material, as a result the latter is subjected to a drag force. This force causes an energy dissipation that is known as fluid damping.

1.1.3 Structural Damping

Rubbing friction or contact among different elements in a mechanical system causes structural damping. Since the dissipation of energy of depends on the particular characteristics of the mechanical system, it is very difficult to define a model that represents perfectly structural damping. The Coulomb-friction model is as a rule used to describe energy dissipation caused by

rubbing friction. Regarding structural damping (caused by contact or impact at joints), energy dissipation is determined by means of the coefficient of restitution of the two components that are in contact. Structural damping is usually estimated by means of measuring but the measured values represent the total damping is the mechanical system. Consequently it is necessary to estimate the values for the other types of damping and to subtract them from the measured value in order to obtain a value of structural damping. Structural damping is much greater than internal damping and it represents a large portion of energy dissipation in mechanical structures.

1.2 VIBRATION SUPPRESSION BY STRUCTURAL DAMPING

Noise and vibrations are generally regarded to be a nuisance in engineering applications. The vibrations of panels and structured members cannot be avoided when the excitation is due to shock or is random over a wide frequency range. The tendency of structures to respond vigorously to all manner of excitation is aggravated by the trends towards lightweight and unit construction with welded joints. The problems of noise and vibration are chronic in missiles, aircrafts, ships, etc., where excessive vibrations can lead to failures by fatigue. The trends towards lightweight and unit construction are giving rise to similar problems in buildings, particularly with pre-stressed concrete construction, which has very little damping.

Vibration and noise in a dynamic system can be reduced by a number of means. These can be broadly classified into active, passive and semi-active methods. Active control involves the use of certain active elements such as speakers, actuators and microprocessors to produce an 'out of phase' signal to electronically cancel the disturbance. The traditional passive control method

for air-borne noise includes the use of absorbers, barriers, mufflers, silencers, etc. For reducing structural vibration and noise, several methods are available. Sometimes just changing the system's stiffness or mass to alter the resonance frequencies can reduce the unwanted vibration as long as the excitation frequencies do not change. But in most cases, the vibrations need to be isolated or dissipated by using isolator or damping materials. In semi-active methods, active control is used to enhance the damping properties of passive elements. The full- scale implementation of active and semi-active methods is costly and complex. Passive damping using viscoelastic materials is simpler to implement and more cost effective than semi-active and active techniques. This thesis deals with the application of viscoelastic damping materials for passive vibration and noise control.

Damping refers to the extraction of mechanical energy from a vibrating system usually by conversion into heat. Damping serves to control the steady state resonant response and to attenuate traveling waves in a structure. There are two types of damping: material damping and system damping. Material damping is the damping inherent in the material while system or structural damping includes the damping at the supports, boundaries, joints, interfaces, etc., in addition to material damping. Passive damping as a technology has been dominant in the non-commercial aerospace industry since the early 1960s. Advances in the material technology along with newer and more efficient analytical and experimental tools for modeling the dynamical behavior of materials and structures have led to many applications such as inlet guide vanes for jet engines, helicopter cabins, exhaust stacks, satellite

structures, equipment panels, antenna structures, truss systems, and space stations, etc.

When viscoelastic materials are used in vibration control, they are arranged so that they are subjected to shear or direct strains.

The concern about passengers' comfort in vehicles has been increasing along the years. To improve it, damping and absorption materials are currently available. However, their benefits usually imply higher costs and additional weight, resulting in additional fuel consumption. In this context, the challenge is to balance the need to reduce the mass and cost with the need to improve the comfort. So, the components of the vehicles have to be optimized and surface damping materials and treatments must be developed to meet the challenge.

Structural damping also known as surface damping reduces both impact-generated and steady-state noises at their source. It dissipates vibration energy in the structure before it can build up and radiate as sound. Damping, however, suppresses only resonant motion. Forced, non-resonant vibration is rarely attenuated by damping, although application of damping materials sometimes has that effect because it increases the stiffness and mass of a system. A damping treatment consists of any material (or combination of materials) applied to a component to increase its ability to dissipate mechanical energy. It is most often useful when applied to a structure that is forced to vibrate at or near its natural (resonant) frequencies, is acted on by forces made up of many frequency components, is subject to impacts or other transient forces, or transmits vibration to noise-radiating surfaces. Although all materials exhibit a certain amount of damping, many (steel, aluminum, magnesium and glass) have so little internal damping that their resonant

behavior makes them effective sound radiators. By bringing structures of these materials into intimate contact with a highly damped, dynamically stiff material, it is possible to control these resonances. Of the common damping materials in use, many are viscoelastic; that is, they are capable of storing strain energy when deformed, while dissipating a portion of this energy through hysteresis. Several types are available in sheet form. Some are adhesive in nature and others are enamel-like for use at high temperatures.

A material's ability to dissipate its vibration energy through internal friction, which converts the energy to heat, particularly in structural applications, is referred to as mechanical damping. The damping of structural components and materials is often a significantly overlooked criterion for good mechanical design. The lack of damping in structural components has led to numerous mechanical failures over a seemingly infinite multitude of structures. However, apart from the design itself, it is frequently necessary to use techniques that lower the level of noise and vibration in the product for industrial application.

Many researchers in noise and vibration areas have focused on developing an effective method of noise suppression against vibrating structures using viscoelastic material. Examples include damping sheets on the body structure of passenger cars, airplanes, ships ducts in buildings and electric appliances. Passive damping treatments are widely used in engineering applications in order to reduce vibration and noise radiation. Passive damping layers are either used as a free or unconstrained layer over the vibrating body or as a constrained layer sandwiched between the top/bottom surface of the vibrating system and a covering layer of comparatively higher stiffness

(usually steel/aluminium foil). In general, viscoelastic materials of high shear modulus are chosen for free layer damping, whereas in constrained layer damping the viscoelastic materials are carefully chosen such that in the range of working frequency they are closer to the rubbery phase and have low shear modulus.

Surface damping treatments are a way for vibration reduction, usually associated to sheet metal structure vibration, by means of passive techniques. Surface damping treatments are classified according to whether the damping material is subjected to extensional or shear deformation and are referred to as extensional, unconstrained or free layered damping (FLD) and as shear or constrained layer damping (CLD) treatments, respectively.

In the present work, experimental tests were carried on different types of rubber materials can be used as damping layers for the structures.

1.3 DAMPING MATERIALS

Although all materials exhibit a certain amount of damping, many (steel, aluminum, magnesium and glass) have so little internal damping that their resonant behavior makes them effective sound radiators. By bringing structures of these materials into intimate contact with a highly damped, dynamically stiff material, it is possible to control these resonances.

The usual approach in the application of damping treatments to structures is to optimize the system for maximum damping only. The lack of damping in structural components has lead to numerous mechanical failures over a seemingly infinite multitude of structures. For accounting the damping effects, lots of research and efforts have been done in this field to suppress vibration and to reduce mechanical failures. Since, it was discovered that

damping materials could be used as treatments in damping to structures to improve damping performances. There has been a flurry of on-going research over the last decades to either alter existing materials or develop entirely new materials to improve the structural dynamics of components to which damping material could be applied. The most common damping materials available on the current market are viscoelastic materials. Viscoelastic materials are generally polymers which allow a wide range of different compositions resulting in different material properties and behaviour.

The common damping materials in use, many are viscoelastic; they are capable of storing strain energy when deformed, while dissipating a portion of this energy through hysteresis. Several types are available in sheet form. Some are adhesive in nature and others are enamel-like for use at high temperatures.

Since there are several types of damping but most of damping materials in the market provided by various manufactures belongs to hysteretic damping. The damping treatment technique is important in vibration control.

1.4 VISCOELASTIC MATERIALS

Viscoelastic materials are not purely elastic materials because, in reality, all materials deviate from Hooke's law in some way. Viscoelastic materials have elements of both of elastic and viscous properties. Whereas elasticity is usually the result of bond-stretching along crystallographic planes in an ordered solid, viscoelasticity is the result of the discussion of atoms or molecules inside of an amorphous material, e.g., glasses, rubbers and high polymers.

Viscoelastic Material Characterization Materials for which the relationship between stress and strain depends on time are called viscoelastic. These materials are rubber-like polymers composed by intertwined and cross-linked molecular chains and during the deformation the internal molecular interactions that occur give rise to macroscopic properties such as energy dissipation. This mechanism is the basis of the viscoelastic damping treatments. In general, the constitutive behavior of viscoelastic material depends upon:

    a). The frequency

    b). Working temperature

    c). Amplitude and

    d). Type of excitation.

For simplicity, the amplitude and type of excitation are often overlooked since these effects are of reduced importance. However, the frequency and temperature dependence are of great importance. The temperature is an important environmental factor that affecting the dynamic properties of damping materials. The first region is the glassy state where the material has very large storage modulus but very low damping, once that the loss modulus is small. In the transition region, the material changes from a glassy state to a rubbery state and the material modulus decreases with increasing temperature. In this region, usually, the loss factor achieves its maximum. In the rubbery state the storage modulus and loss factor take low values and vary slowly with the temperature. Lastly, in the own region the loss factor reaches very high values while material storage modulus decreases.

Apart from temperature, also the vibration frequency has a significant effect on the damping and dynamic modulus of viscoelastic materials. The variation of the modulus and loss factor of a typical high damping material with frequency over a range of three to five decades shows that for a material without the own region, the effect of increasing temperature on the storage modulus is similar to the effect of reducing frequency.

The knowledge of the constitutive behavior of viscoelastic materials is extremely important in the choice of a viscoelastic material for a given application. Therefore, the loss factor peak should ideally correspond to the standard temperature for the system in function. Ideally, the material should also have a broad loss factor peek, in order to exhibit good damping properties for a wide range of temperatures.

The properties of viscoelastic materials are also affected by environmental factors such as humidity and this limits the efficiency of these materials. These dependencies introduce serious difficulties in the dentition of an accurate model able to simulate the dynamic behavior of the damped structure. For this reason, isothermal conditions are usually assumed and only the frequency dependence is taken into account. The temperature frequency superposition principle forms the basis of reduction of the three dimensional relation between the modulus (loss factor), frequency and temperature to a two dimensional one. This involves the use of the reduced frequency or the reduced temperature, which combines the effects of frequency and temperature by the use of shift factors.

However, in this work, the main interest is the use of viscoelastic materials in damping treatments where the energy loss comes from the shear

deformation energy of the viscoelastic material layer which is partially dissipated in the form of heat. Viscoelastic treatments are very efficient solutions as damping mechanisms for light structures but its design and analysis are quite difficult. One of these difficulties is the frequency and temperature dependence and in this chapter the constitutive properties of general viscoelastic materials is studied in order to understand the behavior of these complex materials and achieve the optimal viscoelastic damping treatment.

In this work, viscoelastic materials like Natural rubber, Nitrile rubber and Neoprene rubber with 40, 50 and 60 'shore A' hardness are taken into consideration.

1.5 TYPES OF RUBBERS SELECTED

1.5.1 Rubber

Rubber is a polymer with the property of elasticity which, when modified and strengthen by a curing process called vulcanization, is known as a "Thermoset Elastomer". Each of the monomers which link to form the polymer is usually made of carbon, hydrogen, oxygen and/or silicon.

1.5.2 Natural Rubber (NR)

It is also called India rubber, as initially produced, consists of polymers of the organic compound isoprene, with minor impurities of other organic compounds plus water. Malaysia is one of the leading producers of rubber. Forms of polyisoprene that are used as natural rubbers are classified as elastomers. Natural rubber is used by many manufacturing companies for the production of rubber products. Currently, rubber is harvested mainly in the

form of the latex from the rubber tree. The latex is a sticky, milky colloid drawn off by making incisions into the bark and collecting the fluid in vessels in a process called "tapping". The latex then is refined into rubber ready for commercial processing. Natural rubber is used extensively in many applications and products, either alone or in combination with other materials. In major areas latex is allowed to coagulate in the collection cup. The coagulated lumps are collected and processed into dry forms for marketing. In most of its useful forms, it has a large stretch ratio and high resilience, and is extremely waterproof.

The most common properties of rubber are its elasticity, resistance to water and its use as an electrical insulator. An interesting reaction of natural rubber is its combination with sulphur. This is known as vulcanization. This reaction converts the plastic and viscous nature of raw rubber into elastic. Vulcanized rubber will have very high tensile strength and comparatively low elongation. Its hardness and abrasion resistance also will be high when compared to raw rubber. Because of the unique combination of these properties, natural rubber finds application in the manufacture of a variety of products.

The main use of natural rubber is in automobiles. In developed countries nearly sixty per cent of all rubber consumed is for automobile tyres and tubes. In heavy duty tyres, the major portion of the rubber used is NR. In addition to tyres a modern automobile has more than 300 components made out of rubber. Many of these are processed from NR. Uses of NR in hoses, footwear, battery boxes, foam mattresses, balloons, toys etc., are well known.

In addition to this, NR now finds extensive use in soil stabilization, in vibration absorption and in road making. A variety of NR based engineering products are developed for use in these fields.

The trade name for Natural Rubber is ISNR-20, RMA-4 (high viscosity), RMA-5 (low viscosity). The material has outstanding resilience (low damping), high tensile strength (>20 MPa), superior resistance to tear and abrasion, excellent rebound elasticity (snap), good flexibility at low temperature and excellent adhesion to fabric and metals. They were posse's poor resistance to heat, ozone and sunlight (due to highly unsaturated rubber), very little resistance to oil, gasoline and hydrocarbon solvents. Curing package satisfies for this (i) CBS- 0.70 phr (primary accelerator) (ii) TMTD - 0.10 phr (secondary accelerator) (iii) S - 2.25 phr. Geometrical Isomerism of natural rubber is shown in Fig. 1.1.
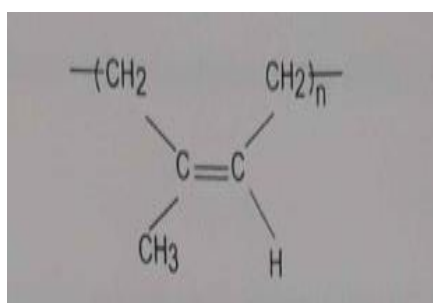
Fig. 1.1 Geometrical isomerism of Natural rubber

There is a bending back of the successive isoprene units, giving the molecules coiled structure, which gives high elongation. They are widely used in application requiring high fatigue life because of its ability to crystallize under strain. Plasticity Retention Index (PRI) is a measure of the resistance of raw rubber to oxidation on heating and is usually expressed in percentage.

1.5.3 Nitrile Rubber (NBR)

It is also known as Buna-N, Perbunan, acrylonitrile butadiene rubber, and NBR is a synthetic rubber copolymer of acrylonitrile (ACN) and butadiene. Trade names include Nipol, Krynac and Europrene.

Nitrile butadiene rubber (NBR) is a family of unsaturated copolymers of 2-propenenitrile and various butadiene monomers (1, 2-butadiene and 1, 3-butadiene). Although its physical and chemical properties vary depending on the polymer's composition of nitrile, this form of synthetic rubber is unusual in being generally resistant to oil, fuel, and other chemicals (the more nitrile within the polymer, the higher the resistance to oils but the lower the flexibility of the material).

It is used in the automotive and aeronautical industry to make fuel and oil handling hoses, seals, grommets, and self-sealing fuel tanks, since ordinary rubbers cannot be used. It is used in the nuclear industry to make protective gloves. NBR's ability to withstand a range of temperatures from −40 to 108 °C (−40 to 226 °F) makes it an ideal material for aeronautical applications. Nitrile butadiene is also used to create moulded goods, footwear, adhesives, sealants, sponges, expanded foams, and floor mats.

Its resilience makes NBR a useful material for disposable lab, cleaning, and examination gloves. Nitrile rubber is more resistant than natural rubber to oils and acids, and has superior strength, but has inferior flexibility. Nitrile gloves are therefore more puncture-resistant than natural rubber gloves,

especially if the latter are degraded by exposure to chemicals or ozone. Nitrile rubber is less likely to cause an allergic reaction than natural rubber.

Properties of NBR depend on ACN content in the polymer. In general, as high ACN content increases the oil resistance and abrasion resistance whereas low ACN content increases low temperature flexibility and resilience. When Nitrile is modified by PVC resins, its resistance to weather and sunlight improves considerably without sacrificing oil-resisting properties. PVC/Nitrile is similar to neoprene, in general, however it is much inferior to CR in adhesion to fabrics metals. Carboxylated Nitrile (XNBR) is generally tougher and more resistant to tear and abrasion than conventional Nitrile, but it is less resilient and flexible at low temperature. The curing packages for Sulphur-system with and without peroxide are given in the Tables 1.1 and 1.2 respectively.

Table 1.1 Curing package for Sulphur-system

1	NBR (33% ACN content)	100
2	S	0.7-1.0 (Lower than used in NR because solubility of sulphur is less in NBR than NR which hinders uniform dispersion. So, sulphur is added usually in the early stage of mixing)
3	ZnO	5.0
4	Stearic Acid	1.0
5	TMTD	-
6	CBS	1.0

Table 1.2 Peroxide cured in special cases

	ASTM Oils			Fuels	
	No.l	No.2	No.3	A	B
Aniline point, UC	124	93	70	45	0

Oil with lower aniline point (ASTM oil No. 3) which is having aniline point 70°C) is more polar or aromatic and therefore swells nitrile rubber to a greater extent.

1.5.4 Neoprene Rubber (CR) / Polychloroprene

It is a family of synthetic rubbers that are produced by polymerization of chloroprene. Neoprene exhibits good chemical stability and maintains flexibility over a wide temperature range. Neoprene is sold either as solid rubber or in latex form, and is used in a wide variety of applications, such as laptop sleeves, orthopedic braces (wrist, knee, etc.), electrical insulation, liquid and sheet applied elastomeric membranes or flashings, and automotive fan belts. Neoprene is produced by free-radical polymerization of chloroprene. In commercial production, this polymer is prepared by free radical emulsion polymerization.

Trade names for Neoprene are Bayprene, Butaclor, Duprene (DuPont, USA). It has good inherent flame resistant, moderate resistance to oil and gasoline, excellent adhesion to fabrics and metals, very good resistance to weather, ozone and natural ageing, good resistance to abrasion and flex

cracking, very good resistance to alkalis and acids but it has poor to fair resistance to aromatic and oxygenated solvents, limited flexibility at low temperature. Neoprenes are classified in three groups. Sulphur-modified (G Type): (i) increased tear strength (ii) increased resilience. Mercaptan modified (W Type): (i) superior to heat and compression set (ii) greater storage stability and more crystalline resistant. T-type- closely related to the W type and contain polymer gel fraction to improve behaviour. They are crystallization resistant and do not require organic accelerators to cure. They have low nerve and shrinkage. Geometrical Isomerism of neoprene is shown in Fig. 1.2.
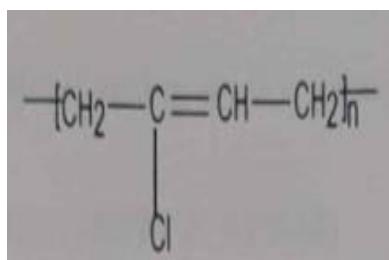
Fig. 1.2 Geometrical isomerism of Neoprene

Curing package for G-type - 4 parts of light calcined MgO + 5 parts ZnO and thio-urea is used to speed up the curing. For W-type - MgO + ZnO + organic accelerator and thio-urea at 0.5 to 1.0 part is probably economical. Polymers with a high degree of crystallization are ideal for adhesive which gives instantaneous contact adhesion and high cohesive force.

1.6 TESTING OF RUBBER

Testing of various rubber products will be carried out to evaluate the properties. The quantity of properties will be checked by mechanical testing and the quality of the products will be checked by non-destructive testing.

1.6.1 Non-Destructive Testing

Non-destructive testing can be defines as a test which will not damage the material being tested. It plays an important role in evaluating quality of the materials. Even though, there exists different type of non-destructive testing methods; Ultrasonic test is most useful for evaluation of entrapped gas in rubber products. In ultrasonic testing, pulse echo method is mainly used for determination of air cavities, in the rubber moulded products. Low frequency normal probes with 0.25 to 0.5 MHz frequency are used in ultra-sonic testing.

1.6.2 Reasons for Testing of Rubbers

Rubber is a complex material which exhibits a unique combination of physical properties. In addition virtually infinite number of vulcanized rubber compounds is possible. For quality control, non-destructive methods should be simple, rapid and inexpensive relate to product performance. For producing design data, the need is for tests which give material properties in such a form that they can be applied with confidence to a variety of configurations. This implies very considerable understanding of the way material properties vary with geometry, time, etc. Extreme speed and cheapness are of relatively minor importance, there is little interest in non-destructive methods. For complex and long-running tests, automation may be desirable. For predicting service performance, the essence of the test must be that it relates to service-the more relevant the test to service conditions, the more satisfactory it is likely to be. Extreme speed and cheapness are less likely to be important but there is a need for test routines, which are not excessively complex. Non-destructive methods may be acceptable. For investigating failures, one should know what to look for, to prove that it needs, more than anything, a test which discriminates well.

There is often no need for absolute accuracy or in some cases even relevance to service. There is nothing in black and white about attributing these requirements to the reasons for testing, but they indicate the emphasis, which usually applies in each case.

1.6.3 Rubber vs. Other Engineering Material

Rubber is highly deformable exhibiting virtually complete recovery. It is virtually incompressible with bulk modulus some thousand times greater than Shear and Young's modulus. Possibility of variation in properties being many implies that standard grade hardly exist and one must evaluate every rubber compound. Structure of rubber and their sensitivity will change in compounding and processing. Property variation from batch to batch makes difficulty in quality control problem. Physical testing procedures for metal and engineering materials are markedly different from rubber. Rubber testing procedures are unique, quality control procedure from design data are still inadequate.

1.6.4 Test Procedure Development of Rubbers

Standard test methods are developed in different countries and different organizations have their own standard. Such as British BS 901, America ASTM, French NIFT, German DIN 1971, Indian IS and ISO. All measurements are subjected to variability. The sources of variability must be found and make a reliable estimate of its magnitude. From this information there liability of results and their significance can be identified.

1.6.5 Physical and Mechanical Properties of Rubbers

The successful employments of materials in engineering applications are lies on their ability to meet design and service requirements. The capability

of materials to meet these requirements is determined by the mechanical and physical properties. Physical properties such as density, thermal conductivity, electrical conductivity, coefficient of thermal expansion, specific heat, etc. are measured by the methods not requiring the applications of mechanical force, whereas mechanical properties such as stress, strain, and elongation, reduction in area, hardness, fatigue resistance and facture toughness are measured by the application of force and are primly related to forces and deformation.

1.7 RUBBER FOR VIBRATION DAMPING

Vibration often causes undesirable consequences such as unpleasant motion noises and dynamic stresses that lead fatigue, failure of structures, decreased reliability, and degraded performance. A necessary pre-requisite to the control of the vibrations of a mechanical system is an understanding of the detailed dynamic behaviour of the system under excitation by forces at various points.

Vibration is ubiquitous and everything vibrates. It is only occasionally that the vibrations occur at a sufficiently high level to be of concern in everyday life. Commonly, vibration is of concern when they have to deal with Vibrating Engines in their problems. Earthquakes of various magnitudes occur frequently worldwide, but usually only the most severe ones that potentially affect human lives are of utmost concern. Similarly Engines of all types vibrate, usually out of necessity, but it is only when the vibrations reach particularly severe levels that remedial action must be taken.

1.8 GENERAL THEORY OF VIBRATION

The study of vibration is concerned with the oscillatory motions of bodies and the forces associated with them. All bodies possessing mass and

elasticity are capable of vibration. Thus, most engineering machines and structures experience vibration to some degree, and their design generally requires consideration of their oscillatory behaviour.

There are two classes of vibrations: Free and Forced. Free vibration takes place when a system oscillates under the action of forces inherent in the system itself. The system under free vibration will vibrate at one or more of its natural frequencies, which are properties of the dynamical system established by its mass and stiffness distribution. Vibration that takes place under the excitation of external forces is called forced vibration. When the excitation is oscillatory, the system is forced to vibrate at the excitation frequency. If the frequency of excitation coincides with one of the natural frequencies of the system, a condition of resonance is encountered and dangerously large oscillations may result. The failure of major structures such as bridges, buildings, or aero plane wings is an awesome possibility under resonance. Thus, the calculation of natural frequencies is of major importance in the study of vibrations.

As mentioned in the previous section, the necessary prerequisite to control the vibrations of a mechanical system is an understanding of the detailed dynamic behaviour of the system under excitation by forces at various points. A very important and fundamental concept in vibration theory is the number of Degrees of Freedom (DOF) of a system. It indicates the number of independent coordinates required to describe the dynamical behaviour of a system.

A particle's motion in space can be described with the help of six coordinates (three for translational motion and three for rotational motion).

Any physical body consists of an infinite number of particles and therefore the total number of Degrees Of Freedom (DOF) of such a system would be six times the number of particles. There was not much difference, when approximate the modeling of such a body by only DOF and compare the response of such a body with its real counterpart. This has been found to be true in a number of cases but not for all. In fact the nearness in the responses has to be first defined (and thereafter iteratively refined during the response prediction phase) before model the body with reduced number of DOF. Hence traditionally systems with one, two and there after multi-degree of freedom systems under different conditions (end boundary and initial conditions) have been studied in detail. There is a lot of similarity in a single and a multi-degree of freedom system, and so by studying a single DOF system results a fairly good idea about the fundamental concepts of vibration. The major difference in a single and multi-degree DOF system lies in the solution of the equations found from their dynamical response. Single DOF system direct mathematical solutions were exist and for multi DOF system numerical methods of solution are often used.

1.8.1 Single Degree of Freedom System (SDOF)

Fig. l.3 shows any physical body approximated by a single DOF is represented mathematically. The mass of the body is lumped together and is represented by 'm'. Whenever a body is disturbed from its equilibrium position an internal opposing force develops in it to and tries to bring it back to equilibrium. This internal force per unit displacement is called stiffness. For a spring it is the same as spring stiffness (k), while for a shaft subjected to torsion it is equal to GJ/L. Stiffness is shown as spring stiffness (for easiness

to tackle mathematically), but its value is equal to the body's stiffness.
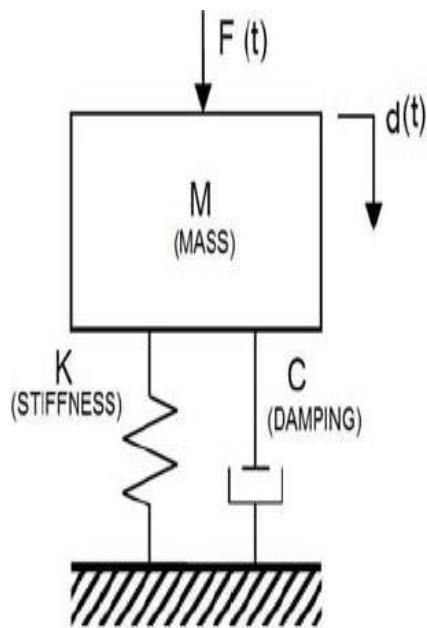
Fig. 1.3 A single degree of freedom system

It is common knowledge that anybody in nature once subjected to vibration (and further no disturbing force acts on it) does not sustain the same forever. This means that the vibrational energy given to the body is dissipated away in some form and thereby brings the body back to equilibrium. Mathematically the simplest form of representing this is the viscous damper. It is represented by, 'c', called the viscous damping coefficient. It is equal to force per unit velocity, and has units Newton per meter per second.

Restricted the motion of the above system to only vertical motion and there by require only one coordinate to describe its motion completely (W). The equation of motion of this body for a given force acting on it is written as follows.

The force on the mass, resulting from elongation of the spring, is

$$F_s = -KW$$

And the force due to movement of the viscous damper is

$$F_{d=\frac{-cd(W)}{dt^2}}$$

The negative sign is because the spring and the damper force oppose the motion of the body. With the forces considered positive in the positive direction of displacement (which is arbitrarily fixed upwards), Newton's second law gives

$$F + F_s + F_d = \frac{md^2(W)}{dt^2}$$

On solving this for a given force results the dynamic response of the body under free vibrations the force 'F' acting on the body is zero. For a SDOF system the natural frequency is given by

$$F_n = \frac{1}{2\pi} * \frac{\sqrt{k}}{m}$$

A general rule is that the number of degree of freedom of a system is equal to number of degrees of freedom of the system. The important point about this discussion was to introduce the terms of stiffness and damping. Because a body possesses stiffness of some magnitude, it returns to its equilibrium position when it is slightly disturbed from the same. Because a body has ways to dissipate its vibrational energy in some form (sound waves, heat etc.), we incorporated this into damping. Mathematically damping need not be represented by viscous damper type alone. In fact other types such as friction damping, hysteric damping etc. do exist. The basic idea of any mathematical model is to accurately represent the physical phenomena and also be able to solve the equations resulting from it. Hence many researchers trying to accurately represent damping tend to use one of the above said

mathematical models repetitively i.e. either series or parallel combination.

1.8.2 Terminology and Mathematical Background of Vibration

Although a vibration isolator will provide some degree of shock isolation, and vice Versa, the principles of isolation are different. Shock and vibration requirements should be analyzed separately. In practical situations, the most potentially troublesome environment, whether it may be vibration or shock, generally dictates the design of the isolator. In other applications where both are potentially troublesome, a compromise solution is possible. Fig. 1.4 shows oscillating spring mass system and graphical representation of vibratory responses.
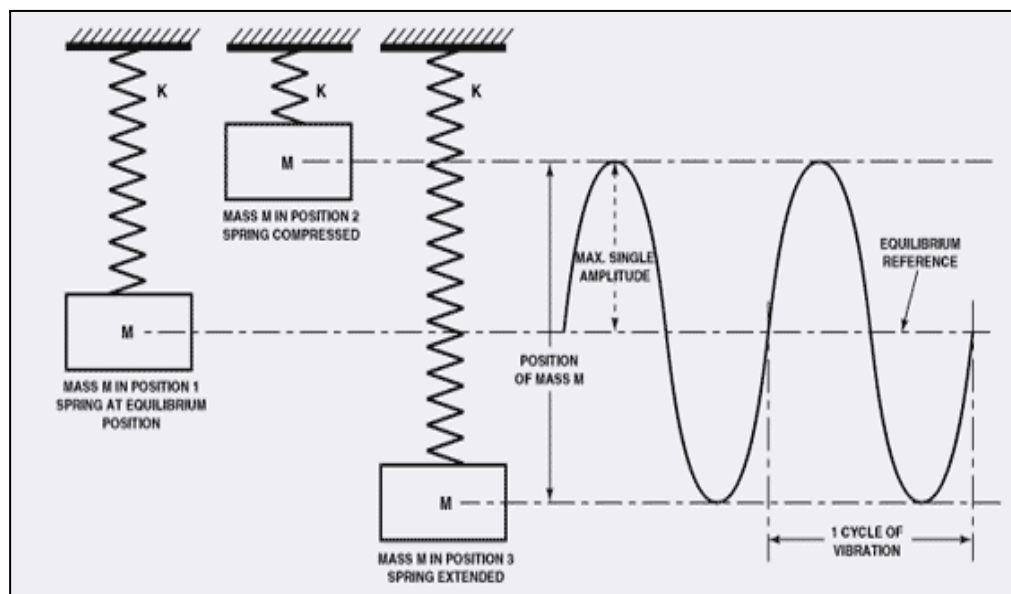
Fig. 1.4 Schematic of oscillating spring mass system and graphical representation of vibratory responses

Before selection of a vibration and/or shock isolator can be made, the engineer should have a basic understanding of the following definitions, symbols, and terms:

- **Vibration:** A magnitude of force, displacement, or acceleration, which oscillates about some specified reference where the magnitude of the force, displacement, or acceleration is alternately smaller and greater than the reference. Vibration is commonly expressed in terms of frequency (cycles per second or Hz) and amplitude, which is the magnitude of the force, displacement, or acceleration.

- **Frequency (f):** Frequency may be defined as the number of complete cycles of oscillations which occur per unit of time and represented in hertz (Hz).

- **Period (A):** The time required to complete one cycle of vibration.

- **Forcing Frequency (f_d):** Defined as the number of oscillations per unit time of an external force or displacement applied to a system.

- **Natural Frequency (f_n):** Natural frequency may be defined as the number of oscillations that a system will carry out in unit time if displaced from it equilibrium position and allowed to vibrate freely.

$$f_n = \frac{1}{2\pi} * \frac{\sqrt{k}}{m}$$

$$f_n = \frac{1}{2\pi} * \frac{\sqrt{kg}}{W}$$

$$f_n = 3.13 \frac{\sqrt{K}}{W}$$

Natural frequency in terms of static deflection without damping

$$f_n = 3.13 \frac{\sqrt{1}}{\Delta s}$$

Also, natural frequency for torsional vibration without damping

$$f_n = 3.13 \frac{\sqrt{k_r}}{I}$$

When damping is considered,

$$f_n = \frac{1}{2\pi} \sqrt{\frac{kg}{W}\left[1 - \left(\frac{c}{c_c}\right)^2\right]}$$

- **Amplitude:** The amplitude of a harmonic vibration such as displacement, velocity, or acceleration is the zero to peak value corresponding to the maximum magnitude of a harmonic vibration time-history.

- **Displacement:** Displacement is a vector quantity that specifies the change of the position of a body or particle and is usually measured from the mean position or equilibrium position. In general it can be represented by a translation or rotation vector or both. The units of the displacement arc mm, cm, inch, feet etc.

- **Velocity:** Velocity is a vector that specifies the time rate change of displacement with respect to a frame of reference.

- **Acceleration:** It is a vector that specifies the time rate of change of velocity with respect to a frame of reference. The acceleration produced by the force of gravity, which varies with the latitude and elevation of the point of observation, is given by $g = 980.665$ centimeters per second$^2 = 386.093$, in/sec$^2 = 32.1739$ ft/sec^2, which has been chosen as a standard acceleration due to gravity.

- **Deflection:** It is defined as the distance a body or spring will move when subjected to a static or dynamic force, F.

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- **Spring Stiffness:** Described as a constant which is the ratio of a force increment to a corresponding deflection increment of the spring.

- **Elastic Center:** The elastic center is defined as a single point at which the stiffness of an isolator or system isolators can be represented by a single stiffness value.

- **Damping:** It is the phenomenon by which energy is dissipated in a vibratory system. Three types of damping generally encountered arc coulomb, hysteresis and viscous.

- **Coulomb Damping:** It is the damping force in a vibratory system is constant and independent of the position or velocity of the system, the system is said to have coulomb or dry friction damping.

- **Hysteresis (Inherent) Damping:** Damping which results from the molecular structure of a material when that material is subjected to motion is referred to as hysteresis damping. Elastomers are good examples of materials which possess this type of damping.

- **Viscous Damping:** If any particle in a vibrating body encounters a force which has a magnitude proportional to the magnitude of the velocity of the particle in a direction opposite to the direction of the velocity of the particle, the particle is said to be viscously damped. This is the easiest type of damping to model mathematically. All of the equations in this text are based on use of a viscous damping coefficient. Although most isolators do not use viscous damping, equivalent viscous damping usually yields excellent results when modeling systems.

- **Damping Coefficient (C):** Damping for a material is expressed by its

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damping coefficient.

- **Critical Damping (C_c):** A system is said to be critically damped when it is displaced from its static position and most quickly returns to this initial static position without any over-oscillation. The damping coefficient required for critical damping can be calculated using:

$$c_c = 2\sqrt{KM}$$

- **Damping Factor:** It is the ratio of Damping Coefficient (C) and Critical Damping **(Cc)** and is a dimensionless quantity.

- **Resonance:** When the forcing frequency coincides with the natural frequency of a suspension system, this condition is known as resonance.

- **Transmissibility:** It is defined as the ratio of the dynamic output to the dynamic input.

$$T = \sqrt{\frac{1 + \left(2\frac{f_d}{f_n} * \frac{c}{c_c}\right)^2}{\left(1 - \frac{f_d^2}{f_n^2}\right)^2 + \left(2\frac{f_d}{f_n} * \frac{c}{c_c}\right)^2}}$$

For negligible damping T becomes:

$$T = \left| \frac{1}{\left(1 - \left(\frac{f_d}{f_n}\right)\right)^2} \right|$$

When resonance occurs, and, T is at its maximum becomes:

$$T_{max} = \frac{1}{2 * \frac{c}{c_c}}$$

- **Shock:** Defined as a motion in which there is a sharp, nearly sudden

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change in velocity. Examples of this are a hammer blow on a anvil or a package falling to the ground. Shock may be expressed mathematically as a motion in which the velocity changes very suddenly.

- **Shock Pulse:** Shock pulse is a primary disturbance characterized by a rise and decay of acceleration from a constant value in a very short period of time. Shock pulses are normally displayed graphically as acceleration vs. time curves.

- **Shock Transmission:** Shock transmitted to the object subjected to the shock. This can be calculated with the following equation:

Shock transmitted = $G_r = V \frac{(2\pi f_n)}{386} = \frac{V f_n}{61.4}$

In this equation, V represents an instantaneous velocity shock. Most shock inputs can be approximated by an instantaneous velocity shock. See shock isolation section starting on page X for more detail. The associated dynamic linear deflection of an isolator under shock can be determined by the use of the following equation:

$$\Delta_D = \frac{V}{2\pi f_n}$$

1.9 SUMMARY

A brief introduction to damping, structural damping, viscoelastic materials such as Natural, Nitrile, Neoprene rubbers and their basic uses are presented. Benefits and applications of damping materials are discussed. The need of testing of rubber for the present work is explained.

CHAPTER - II

LITERATURE REVIEW

Before going with the investigation, a brief study on papers related to vibration damping was done. Materials for vibration damping are mainly metals and polymers, due to their viscoelastic character. Many authors gave different ideas related to their works on damping characteristics of metals and polymers; structural damping treatments and applications. This chapter reviews the important works done on vibration damping.

Crandall [1970] discussed the fundamental concepts like loss factor and the mathematical modeling of damping. Explains the nature of damping mechanisms and an indication was given of how damping depends on the amplitude and frequency of the cyclic motion. Idealized damping models used in theoretical analyses were described and some limitations noted.

Jones [1974] discussed the simpler and more reliable techniques for measuring the complex modulus properties of elastomeric and other materials, as functions of frequency, temperature and strain, are reviewed. Use is made of the well established "temperature-frequency superposition" principle to reduce the data to a standardized form useful for engineering purposes. Specific examples of the techniques for reducing the data are discussed. Possible future application of the results to automated data processing and reduction is briefly discussed.

Nakra [2000] reviewed the damping mechanisms in materials and their

characterization for viscous, hysteresis, coulomb and viscoelastic types of damping. Surface damping techniques including constrained and unconstrained layer damping methods are discussed. The influence of damping on dynamic behaviour of machine and structures are highlighted.

Amada [1997] described dynamic viscoelastic properties of bamboo in torsion and bending. Damping measured in dry bamboo was relatively small, about 0.01 in bending and 0.02 to 0.03 in torsion, with little dependence on frequency in the audio range. In wet bamboo, damping was somewhat greater: 0.012 to 0.015 in bending and 0.03 to 0.04 in torsion.

Weizhi Wang *et al*. [2003] studied mechanical properties and crystal morphological structures of short glass fiber reinforced dynamically photo-irradiated polypropylene (PP)/ethylene-propylene-diene terpolymer (EPDM) composites by mechanical tests, wide-angle X-ray diffraction, optical microscopy, scanning electron microscopy, Differential scanning calorimeter and thermo gravimetric analyzer respectively. The mechanical properties of PP/EPDM composites, especially the tensile strength were greatly strengthened by dynamically photo-irradiation and the incorporation of SGF. Mechanical properties, namely, tensile strength, tensile modulus at 100% elongation, and hardness had followed up as a function of irradiation dose and degree of loading with Filler. In addition, the electrical and thermal properties composites were evaluated. The results obtained indicate that improvement has been attained in different properties of loaded NBR/EPDM composites with respect to unloaded one for increasing its thermal stability.

Ratna *et al.* [2004] developed three epoxy compositions by using polyether amine hardeners having varying chain lengths of polyethers. Unlike normal epoxies, the compositions show low glass transition temperatures (0–45°C). Dynamic mechanical analysis and time–temperature superposition of the isotherms indicate that they have broad and high loss factor values over broad frequency and temperature ranges suggesting their application as viscoelastic materials in constrained layer damping of structural vibrations.

Xiuying Zhaoa *et al.* [2015] studied Natural rubber (NR)/Nitrile butadiene rubber (NBR)/hindered phenol (AO-80) composites with high-damping properties. The morphological, structural, and mechanical properties were characterized by atomic force micro scopy (AFM), Polarized Fourier Transform Infrared Spectrometer (FTIR), dynamic mechanical thermal analyzer (DMTA), and a tensile tester. Each composite consisted of two phases: the NR phase and the NBR/AO-80 phase. There was partial compatibility between the NR phase and the NBR/AO-80 phase, and the NR/NBR/AO-80(50/50/20) composite exhibited a co-continuous morphology. Strain-induced crystallization occurred in the NR phase at strains higher than 200%, and strain-induced orientation appeared in the NBR/AO-80 phase with the increase of strain from 100% to 500%. The composites had special stress–strain behaviour and mechanical properties because of the simultaneous strain-induced orientation and strain-induced crystallization. In the working temperature range of a seismic isolation bearing, the composite (especially the NR/NBR/AO-80 (50/50/20) composite) presented a high loss factor, high area of loss peak, and high hysteresis energy. Therefore, the NR/NBR/AO-80

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rubber composites are expected to have important application as a high-performance damping material for rubber bearing.

Lin Zang *et al.* [2016] described the preparation and damping properties of an organic–inorganic hybrid material based on nitrile rubber. In the work, new type composites of acrylonitrile butadiene rubber (NBR) and polyurethane-sericite hybrid materials was prepared by melt blending method. The PU-sericite hybrid phase was formed via the reaction of NCO groups of NCO terminated PU prepolymer and OH groups of sericites. It was indicated by dynamical mechanical analysis that the damping property of NBR decreases as the amount of PU increases, whereas the mechanical properties at low temperature are enhanced. When PU of 10 wt% was added in, a better damping property obtained. The damping property of NBR/PU composites would decrease when adding in sericites, however, the mechanical properties at low temperature would be improved. With PU-sericites hybrid added, the compatibility between sericites and NBR/PU composites would be enhanced and the quasi-interpenetrating polymer network structures would be formed, resulting in a better mechanical property of NBR/PU-sericites composites.

Noor Aldeen Bawadukji and Rafi Jabra [2017] studied the preparation and characterization of different formulations of Nitrile Butadiene Rubber (NBR) Krynac 3370F rubber with different contents of three inorganic reinforcing fillers such as conventional N330 carbon black, nanometric aerosil 200 silica and micrometric volcanic tuff.

Junjun Wang *et al.* [2018] discussed improving strength and damping performance of Nitrile Rubber via incorporating sliding graft copolymer (SGC). The micro-structure characterizations reveal that SGC phase is dispersed in NBR matrix fairly uniformly with a distinct inter phase. As SGC content increases, the loss factor of SGC/NBR blends gradually increases. The improved damping properties of SGC/NBR blends are attributed to the intrinsic high damping characteristics of SGC and the formed interfacial hydrogen bonds. In addition, the mechanical properties of SGC/NBR blends are unexpectedly improved. The tensile strength of SGC/NBR (20/100) is increased by 170%, comparing to that of NBR. The significantly increased tensile strength is ascribed to the increased orientation of NBR chains, due to the "pulley effect" of SGC and the successive rupture/re-association of interfacial hydrogen bonds. The high damping and mechanical properties of SGC/NBR blends render them potential in isolation rubber bearings application.

From the literature, it was observed that many of researchers were not concentrated on the viscoelastic materials such as Natural, Nitrile and Neoprene rubbers used specifically for certain applications like damping, insulation, oil resistance etc. The developments of materials such as Natural, Nitrile and Neoprene rubbers of different hardness are in the sense of mechanical, electrical and thermal applications are not yet presented. In the present work, the development of damping materials of different hardness is presented.

CHAPTER - III

OBJECTIVES AND SCOPE

The present work has investigated with the following objectives and scope:

1) To study the mechanical properties of the Natural, Nitrile and Neoprene rubbers.

2) To optimize the parameters like accelerator and carbon black content for vibration damping.

3) To design the experiments using Taguchi.

4) To study the influence of each parameter to the particular response value using SN ratio.

5) To study the most significant factor influencing each response using ANOVA.

The overall aim of the work is to comprehensively assess the effect of each factor on a particular response to enhance the improved structural damping using these three materials with different hardness.

CHAPTER - IV

EXPERIMENTAL DETAILS

In the present work, different viscoelastic materials such as Natural, Nitrile and Neoprene rubbers with different hardness are selected. The details of the instrumentation, experimental setup and the experimental procedures adopted are presented here in this chapter.

4.1 SELECTION OF DAMPING MATERIALS

In this work, the main interest is the use of viscoelastic materials in damping treatments where the energy loss comes from the shear deformation energy of the viscoelastic material layer which is partially dissipated in the form of heat. The viscoelastic materials taken into consideration are Nitrile, Nitrile and Neoprene rubbers.

There are many ingredients in the rubber compounds that can be used to give different properties. All compounds are not same. Rubber compounding is a science to assure required properties by varying the ratios of ingredients and compensating for the interactions. This is why most compounders consider their rubber formulations proprietary. PHR (Parts per Hundred Rubber) is used for the calculation of formulas. The compound ingredients are given as parts per hundred by weight of the rubber polymer.

A rubber compound could be a combination of different ingredients of thousands of different compositions and vendors. Compound formulation of Natural, Nitrile, Neoprene rubbers sheets based on parts per hundred are as

shown in the Tables 4.1 to 4.3 The carbon black content used within the range

of 30 to 65 phr.

Table 4.1 Formulation of Natural Rubber

S.No.	Ingredients	PHR
1	Natural Rubber (NR)	100
2	Zinc Oxide (ZnO)	5
3	Stearic Acid	2
4	Anti-Oxidant	2
5	Carbon Black	30, 50, 65
6	Aromatic Oil	4
7	Sulphur	2
8	Accelerator	1

Table 4.2 Formulation of Nitrile Rubber

S.No.	Ingredients	PHR
1	Nitrile Rubber (NBR)	100
2	Zinc Oxide (ZnO)	5
3	Stearic Acid	1
4	Anti-Oxidant	2
5	Carbon Black	30, 50, 65
6	DOP Oil	5
7	Sulphur	1.5
8	Accelerator	2

Table 4.3 Formulation of Neoprene Rubber

S.No.	Ingredients	PHR
1	Neoprene Rubber (CR)	100
2	Stearic Acid	1
3	Magnesium Oxide	4
4	Anti-Oxidant	2
5	Carbon Black	30, 50, 65
6	Process Oil	4
7	Zinc Oxide (ZnO)	5
8	Accelerator	0.5

The stearic acid (SA) is involved in almost all rubber compounds. It is

used in relatively low amounts (up to 3.0 phr) but has a multifunctional effect on their properties and processing. It is used as a softener and a filler dispersing agent within rubber compounds. As a softener, SA influences the viscosity of filled compound. Compounding materials which form cross-links during vulcanization. The most common are sulphur and peroxides. Curing or vulcanization is a process where the elastomer compound is transformed from a yielding plastic material into an elastic material. This is done by a sparse network of bonds being formed between the molecules of the elastomer material. Normally sulphur is used as a curing agent. Rubber polymers are just entangled hydrocarbon chains than won't hold shape. In 1839, Goodyear discovered that rubber chains can be bonded together by heating the rubber with sulphur, called vulcanization. Bonds of carbon – sulfur – carbon are formed. Antioxidants are used to protect the compound from high temperature while in use and while the compound is being mixed. Carbon Black is one of the most common fillers. This gives the rubber compound physical strength and its black color. Various oils are used to help incorporate all the dry ingredients used in the rubber compounding. They also help to reduce the viscosity of the overall compound to help with molding. Adding more oil can also lower the hardness of the rubber. Thus, lower Shore A compounds will typically have more oil in the formulation. The accelerators consist of complex organic compounds used to speed up the vulcanization. Rubber tensile properties are greatly influenced by proportioning of fillers. All fillers change the main physical properties of rubber and mostly hardness, tensile strength, modulus and abrasive resistance. For filling mixtures the most common criterion is value of the stress under 300% elongation.

4.2 HARDNESS TEST

Hardness is one of the most widely measured properties used to characterize rubber. Two scales are in general use throughout the world – the IRHD (International Rubber Hardness Degree) scale and the Shore scale.

Shore hardness specifies methods for determining the hardness of materials by means of Durometers of two types: type A for softer materials and type D for harder materials, although the ASTM D2240 standard covers the Durometer scales types such as A, B, C, D, DO, O, OO and M. These are used for testing a wider range of materials. The A scale is used for soft rubbers and elastomers, and type C for medium hard rubbers and plastics; both types use a truncated cone shaped indentor. Type A is the most commonly used rubber scale. Type B is used to test moderately hard rubbers and type D is used to test hard rubbers and plastics. Type DO is used for very dense textile windings, type O is used for soft rubbers and medium density textiles and OO is used for low density textile windings and sponge.

Fig. 4.1 shows the Wallace IRHD hardness tester to evaluate hardness of the rubber materials. The tester can be used to find hardness in the range from 0 to 100 IRHD. It is a digital display hardness tester. The specimens for hardness testing were prepared as per ASTM D2240-15 shown in Fig. 4.2. The IRHD test is a non-destructive form of rubber quality test and is the most preferred method for final product inspection in the rubber industry. The IRHD hardness tester is equipped with a spherical indentor, which indents the sample under a minor and major load. The differential indentation depth is measured and tabulated to read directly in 'IRHD' degrees. The standard test method conducted involves pressing a piece of rubber with a known force for

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a given time, and measure how much the rubber indents in that time. The recorded deflection gained is then converted into a scale of degrees.

Fig. 4.1 Hardness Tester

The test specimen shall be at least 6 mm in thickness. The surfaces of the specimen shall be flat and parallel over an area to permit the presser foot to contact the specimen over an area having a radius of at least 6 mm according to the ASTM D2240-15 standards. In the present work the rubber buttons as test specimens prepared with 10 mm thick and 6mm radius. The specimen is first placed on a hard flat surface. The indentor for the instrument is then pressed into the specimen making sure that it is parallel to the surface. Each flat sample was tested in three different places 5 mm apart.

Fig. 4.2 Specimens for Hardness test

The instrument was calibrated before starting and the calibration was rechecked at the end using certified or calibrated test blocks. It is recommended that the hardness range of the test block be approximately the same as that for which the testing machine is used. Rubber hardness test blocks are available in five scales - IRHD (macro), IRHD (micro), shore A, D and M. The test blocks are for use as a check to ensure instruments are functioning properly and read correctly. Test blocks should be returned to Wallace every 12 months for re-calibration. In the present work glass was used as a test block to check instrument calibration. The instrument was to be strictly manufactured as per ASTM and DIN standards.

4.3 TENSILE TEST

Fig. 4.3 shows a KMI Electronic Tensile Tester (Model No.: KMI-201T) having 5000 N loading capacity, maximum cross travel speed of 500 mm/min, clip-on strain gauge type extensometer capacity of 1m length and least count of 0.02 mm with computer aided operating machine provided by software was used for testing.
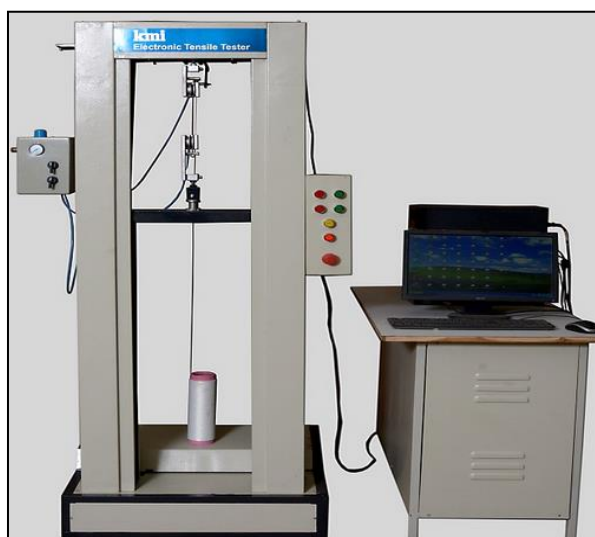

Fig. 4.3 Universal Tensile Testing Machine

Tensile testing rubber specimens were prepared as per ASTM D412 and the tensile strength and elongation at break tests were carried. ASTM D412 references two test methods such as Method A is for dumbbell (dog bone)-shaped specimens, while Method B is for flat cut ring specimens. The standard calls for samples which have not been pre-stressed to be measured for tensile stress, tensile stress at a given elongation, tensile strength, and yield point. The present investigation followed with Method A. The dumbbell specimens were cut using Die C as shown in Fig. 4.5, described in ASTM D412. Die C has an overall length of 115 mm with a narrow section 33 mm long. This provides a gauge length 25 mm long and a gauge width of 6 mm as shown in the Fig. 4.4.
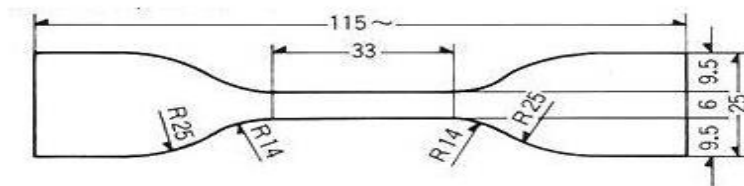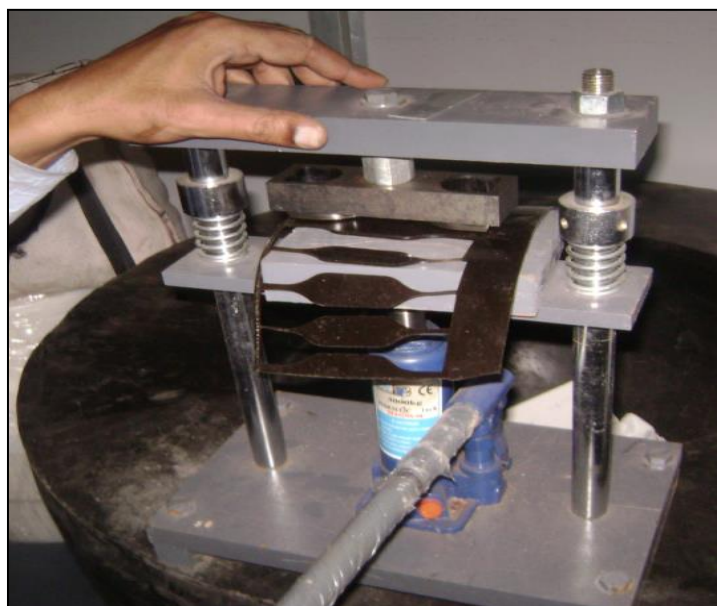

Fig. 4.4 Specimen dumbbell cutting Die size

Fig. 4.5 Specimen dumbbell cutting press

The testing is conducted on dumbbell test pieces, which are punched out of 2 mm test sheets as shown in Fig. 4.6. The test is done in a tensile testing machine using a speed of 500 mm/min. To determine the elongation and the stress at different elongation, an extensometer is also needed. The extensometer can be mechanical with balanced clamps that measure the elongation of the test piece.

Fig. 4.6 Tensile testing rubber specimen

To determine tensile stress, tensile strength and yield point, the dumbbell-shaped sample is to be placed in the grips. Start the machine and note the distance between the bench marks. Record the force at the elongation specified for the test and at the time of rupture. The elongation measurement is made preferably through the use of an extensometer. Once the specimen breaks, measure and record the elongation.

The Tensile Testing Machine is to be calibrated annually. Users should review the accredited calibration certificates annually to see if the device has deviated significantly in terms of accuracy. This mitigates the risk of producing invalid results. The calibration procedures are determined by internationally recognized standards. The locations of the reference points to be calibrated are determined by the standard and checked on an initial run. The verification is then repeated a second time. If the error on each run and the repeatability calculations show error less than 1%, the measurement device

passes and calibration is verified. If the errors are greater than 1%, the service technician will adjust values of the measurement device's calibration manually so that the measurements match the target range of the calibrated device.

4.4 DESIGN OF EXPERIMENTS

A set of experimental work has been designed by Taguchi method. The required responses are dependent upon the arrangement of the input parameters during each experiment. These types of metrics are called an orthogonal array. The values of the process parameters at different levels are mentioned in Table 4.4, such parameters were selected which makes more effects on the desired output. The experiments were arranged in three types of materials (Natural rubber, Nitrile rubber and Neoprene rubber), three levels of hardness (40, 50 and 60 shore A) and three levels of carbon black content (30, 50 and 65 phr). The suitable orthogonal array describes the experiment plan on the basis of degrees of freedom.

In this experiment Signal-to-Noise ratio has been used to examine the effect of each factor on a particular response. The signals show the effect of each factor on the response, whereas noise is the measure of the influence on the deviation from the average responses. S/N ratio is based upon the lower-the-better, larger-the-better and nominal-the better criteria. In this study responses are associated with the tensile strength of the material, which should be high as possible so the larger-the-better criteria has been chosen. The strength of the material which is generally expected to be high is examined by

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum_{i=0}^{n}1/y_i{}^2\right) \qquad (1)$$

Where, $n =$ number of measurements; $y_i =$ response value for each noise factor; $i =$ number of design parameters in this study OA has 9 experiments (L9).

The Orthogonal array is designed by 9 numbers of experiments, so its total Degree of freedom will be $9-1=8$. To study the influence of each parameter to the response value, Analysis of Variance (ANOVA) technique has been used. ANOVA states that total sum of squares of the deviation are equal to the sum of square of standard deviation caused by each input factor.

Table 4.4 Input parameters and levels

Variables	Units	Levels		
		1	2	3
Accelerator	phr	1	2	0.5
Carbon Black Content	phr	30	50	65

4.5 SUMMARY

In this chapter mechanical testing methods and design of experiments were explained. All the equipment used and detailed procedures for conducting tests are explained as per the standards.

CHAPTER - V

RESULTS & DISCUSSION

This chapter deals with the results and discussion of the mechanical properties of rubbers by conducting tests.

5.1 MECHANICAL PROPERTIES OF RUBBERS

The hardness and tensile tests were conducted for all the selected rubbers and results are shown in the Tables 5.1 to 5.3. Hardness was evaluated by IRHD hardness tester shows readings in IRHD. Tensile strength and % elongation at break were conducted by KMI Electronic Tensile Testing Machine with long travel extensometer. Hardness of all the rubber samples is shown in Table 5.1.

Table 5.1 Hardness of rubbers

S.No.	Rubber (Shore A)	Hardness (IRHD)
1	Natural 40	40.6
2	Natural 50	50.2
3	Natural 60	60.8
4	Nitrile 40	40.6
5	Nitrile 50	50.3
6	Nitrile 60	61.4
7	Neoprene 40	40.5
8	Neoprene 50	50.6
9	Neoprene 60	60.4

Within the Natural rubber, Natural 60 shore A shown better hardness than Natural 40 shore A and Natural 50 shore A. Similar trend was observed with Nitrile and Neoprene rubbers. Out of all rubbers, Nitrile 60 shore A shown better hardness.

Tensile strength of all the rubbers is shown in Table 5.2. Within Natural rubber, Natural 60 shore A rubber shown better tensile strength than Natural 40 shore A and Natural 50 shore A. Similar trend was observed with Nitrile and Neoprene rubbers. Out of all rubbers, Neoprene 60 shore A rubber shown better tensile strength. It is due to the more interaction between polymer chain and carbon black fillers. Tensile strength of all rubbers increases with carbon black proportion. This resembles the studies reported by Noor Aldeen Bawadukji and Rafi Jabra, [2017].

Table 5.2 Tensile Strength of rubbers

S.No.	Rubber (Shore A)	Tensile Strength (MPa)
1	Natural 40	9.97
2	Natural 50	13.54
3	Natural 60	16.38
4	Nitrile 40	3.27
5	Nitrile 50	5.76
6	Nitrile 60	9.28
7	Neoprene 40	16.92
8	Neoprene 50	17.29
9	Neoprene 60	20.38

Tables 5.3 shows, out of all the rubbers, the percentage increase in the original length of the sample is observed. The rubber samples having high % elongation at break will be due to the reinforced carbon black filler. The additional cross linking is most apparent in the increase in hardness and increase in tensile strength.

Table 5.3 Elongation at break of rubbers

S.No.	Rubber (Shore A)	Elongation at break (%)
1	Natural 40	488.2
2	Natural 50	463.8
3	Natural 60	447.3
4	Nitrile 40	416.1
5	Nitrile 50	400.4
6	Nitrile 60	350.7
7	Neoprene 40	775.1
8	Neoprene 50	774.0
9	Neoprene 60	431.7

5.2 DESIGN OF EXPERIMENTS

The rubber samples have been prepared at different level of accelerator content and carbon black content using different materials and mechanically tested. Ultimate tensile strength (UTS), hardness (IRHD) and % elongation were chosen as response values. Tables 5.4 describes the results obtained from the Hardness and Tensile at various conditions. The L_9 orthogonal Array (OA) is considered. The actual value for accelerator content and carbon black

content is mentioned in columns 3 and 4 respectively. The response values such as hardness, ultimate tensile strength (UTS) and % elongation at break are mentioned in columns 5, 6 and 7 respectively. The design of experiment was prepared with the help of MINITAB 20.2.0.0.

Table 5.4 Results obtained from hardness and tensile tests for L_9 OA

Test No.	Actual Settings			Response value		
	Material	Accelerator (phr)	Carbon Black	Hardness (IRHD)	UTS (MPa)	% elongation
1	Natural rubber	1	30	40.6	9.97	488.2
2	Natural rubber	1	50	50.2	13.54	463.8
3	Natural rubber	1	65	60.8	16.38	447.3
4	Nitrile rubber	2	30	40.6	3.27	416.1
5	Nitrile rubber	2	50	50.3	5.76	400.4
6	Nitrile rubber	2	65	61.4	9.28	350.7
7	Neoprene rubber	0.5	30	40.5	16.92	775.1
8	Neoprene rubber	0.5	50	50.6	17.29	774.0
9	Neoprene rubber	0.5	65	60.4	20.38	431.7

The response tables and graphs of the S/N ratio for the response values are given in Tables 5.5, 5.6 and Figures 5.1, 5.2 respectively. The optimal factors are obtained at the accelerator 0.5 phr (level 1) and Carbon black content at 65 phr (level 3) when the factors are considered with the response values regarding hardness and UTS whereas the optimal factors are obtained at accelerator content 2 (level 3) and carbon black content at 65 phr (level 3) when the factors are considered for the response value i.e. %elongation at

break. From the results it is clear that by increasing carbon black content response value (hardness) increases. Tables 5.5 and 5.6 shows the rank of the input parameters. Accelerator has 1st rank and carbon black shows 2nd rank which indicate that the most influencing factor is accelerator than carbon black content.

Table 5.5 Response Table for Signal to Noise Ratios (Larger is better)

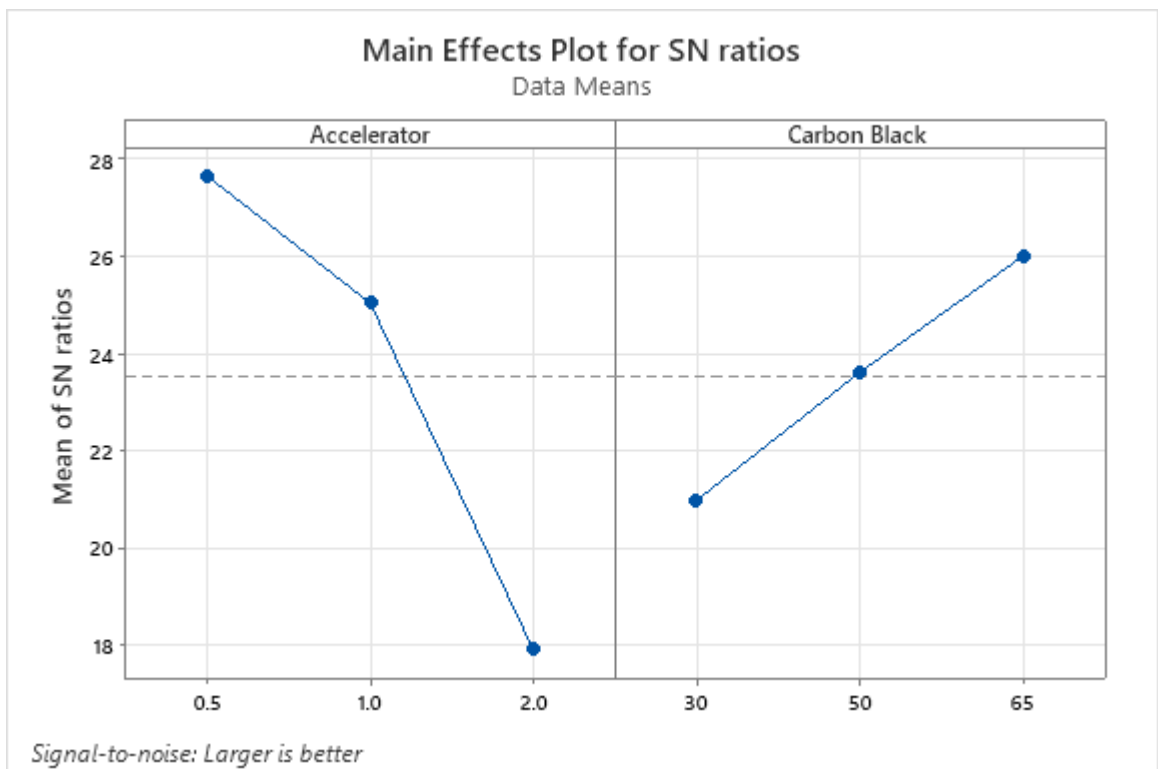| Level	Accelerator	Carbon Black
1	27.63	20.96
2	25.02	23.60
3	17.90	25.99
Delta	9.73	5.03
Rank	1	2

Fig. 5.1 Main effect plot of S/N ratio of accelerator content and carbon black content values for L_9 OA. (Hardness and UTS Vs Accelerator and Carbon black content)

Table 5.6 Response Table for Signal to Noise Ratios (Smaller is better)

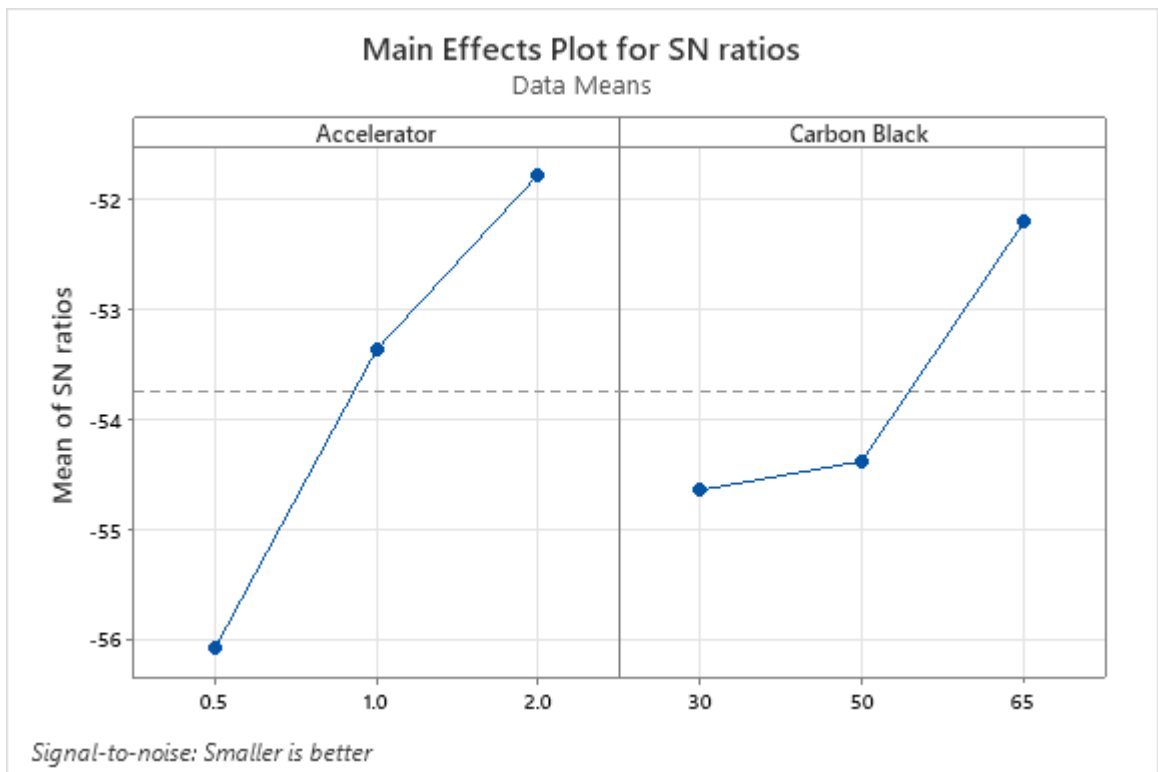| Level	Accelerator	Carbon Black
1	-56.09	-54.65
2	-53.37	-54.38
3	-51.78	-52.20
Delta	4.31	2.44
Rank	1	2

Fig. 5.2 Main effect plot of S/N ratio of accelerator content and carbon black content values for L$_9$ OA. (%elongation at break Vs Accelerator and Carbon black content)

To validate the Taguchi's report, Analysis of Variance (ANOVA) technique has been applied and the percentage contribution of each process parameters on the hardness, UTS and % elongation value is calculated with the help of equation.

Percentage Distribution for Hardness values (PH)
$$= (SS_d)/(SS_T)$$

(2)

SS_d = sum of the squared deviations; SS_T = sum of the squared total.

Table 5.7 shows the analysis of variance (ANOVA) for one of the response value i.e. Hardness. The ANOVA results reported that carbon black acts as a most significant factor. By increasing the carbon black content from 30 to 65 phr, the hardness property of the rubber material improved.

Table 5.7 Analysis of Variance for Transformed Response
General Linear Model (Hardness Vs Accelerator and Carbon black content):

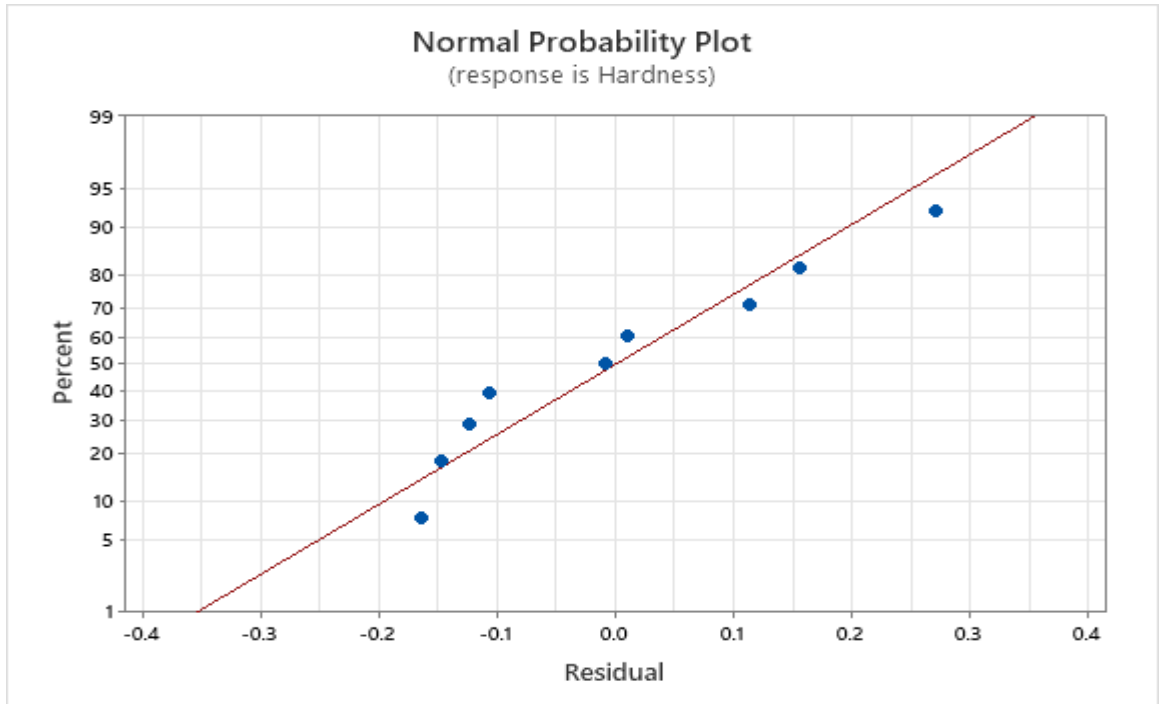| Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Accelerator	2	0.032	0.00%	0.032	0.016	0.34	0.728
Carbon black	2	744.178	99.97%	744.178	372.089	7994.91	0.000
Error	4	0.186	0.03%	0.186	0.047		
Total	8	744.396	100.00%				

Fig. 5.3 Normal Probability Plot from Hardness (IRHD)

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Table 5.8 shows the analysis of variance (ANOVA) for one of the response value i.e. UTS. The ANOVA results reported that accelerator content acts as most significant factor.

Table 5.8 Analysis of Variance for Transformed Response
General Linear Model (UTS Vs Accelerator and Carbon black content)

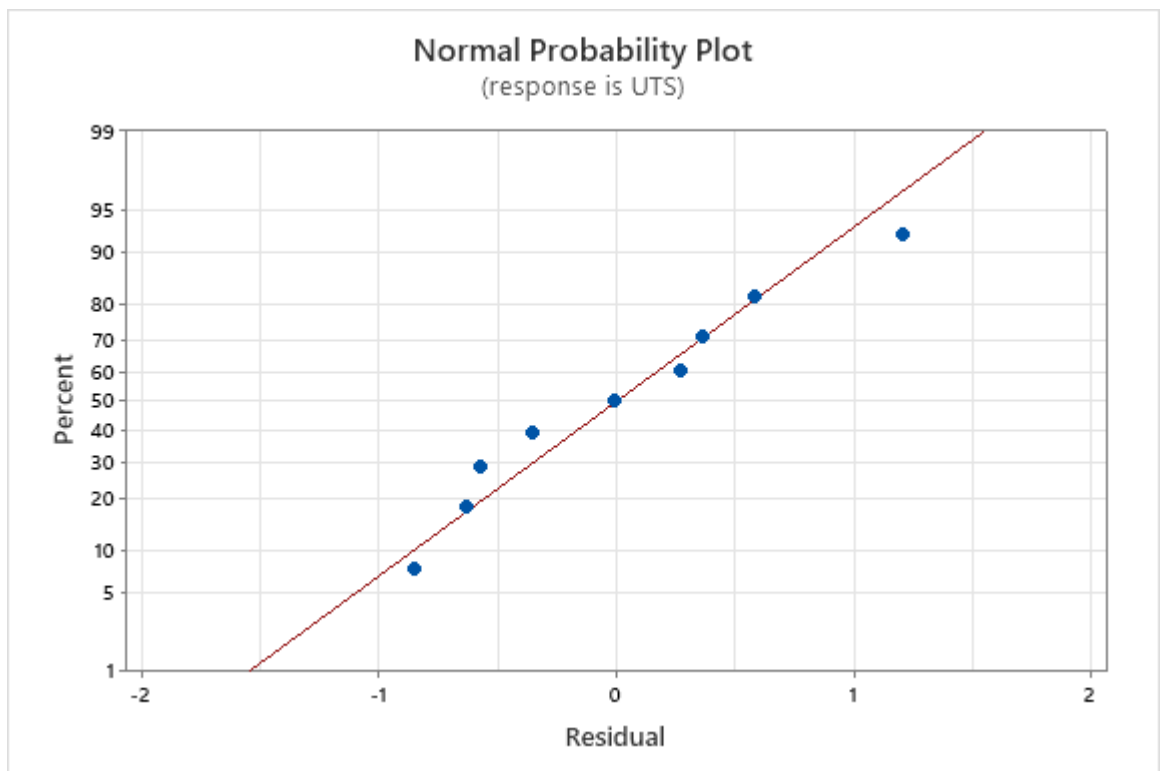| Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Accelerator	2	222.003	82.81%	222.003	111.001	124.97	0.000
Carbon black	2	42.536	15.87%	42.536	21.268	23.94	0.006
Error	4	3.553	1.33%	3.553	0.888		
Total	8	268.091	100.00%				

Fig. 5.4 Normal Probability Plot from UTS (MPa)

Table 5.9 shows the analysis of variance (ANOVA) for one of the response value i.e. % elongation at break. The ANOVA results reported that accelerator content acts as a most significant factor. The second affecting

factor is carbon black content. By decreasing the hardness from 60 to 40 shore
A, the % elongation of the rubber material improves.

Table 5.9 Analysis of Variance for Transformed Response

General Linear Model (%elongation Vs Accelerator and Carbon black content)

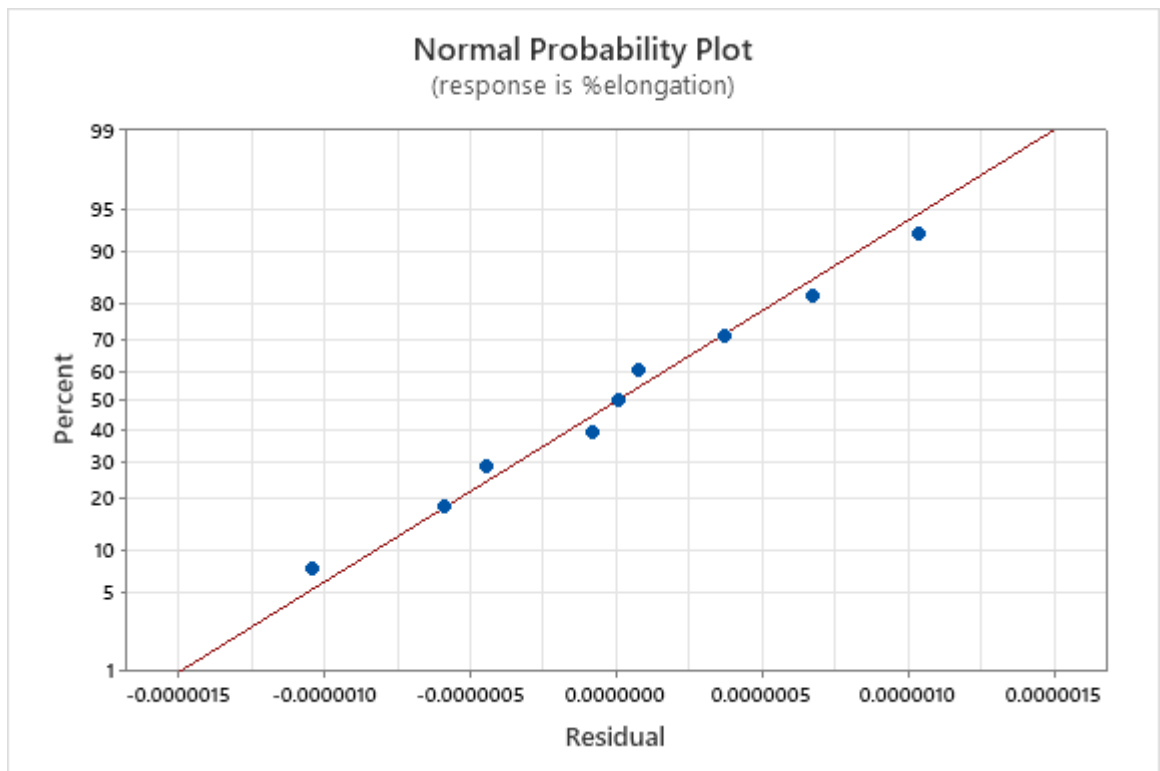| Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Accelerator	2	0.000000	63.56%	0.000000	0.000000	13.20	0.017
Carbon black	2	0.000000	26.81%	0.000000	0.000000	5.57	0.070
Error	4	0.000000	9.63%	0.000000	0.000000		
Total	8	0.000000	100.00%				

Fig. 5.5 Normal Probability Plot from % elongation at break

CHAPTER - VI

CONCLUSIONS AND FUTURE SCOPE

6.1 CONCLUSIONS

In this work the damping materials such as Natural, Nitrile and Neoprene rubbers with different hardness have been developed and these materials were characterized for hardness and tensile strength and they have been analyzed using Taguchi based on the factors like accelerator and carbon black content. Finally the Taguchi report is validated with the ANOVA. From the experimental results shown in the previous chapter, the following conclusions were obtained:

1. From the response tables and graphs of the S/N ratio for the response values, the optimal factors are obtained at the accelerator 0.5 phr (level 1) and Carbon black content at 65 phr (level 3) when the factors are considered with the response values regarding hardness and UTS.

2. Whereas the optimal factors are obtained at accelerator content 2 (level 3) and carbon black content at 65 phr (level 3) when the factors are considered for the response value i.e. %elongation at break.

3. Accelerator is the most influencing factor than carbon black content.

4. The ANOVA results reported regarding hardness (IRHD) that carbon black acts as a most significant factor. By increasing the carbon black content from 30 to 65 phr, the hardness (IRHD) property of the rubber material improves.

5. The ANOVA results reported for the response value i.e. UTS that accelerator acts as most significant factors.

6. The ANOVA results reported for one of the response value i.e. % elongation at break that accelerator acts as a most significant factor. The second affecting factor is carbon black content. By decreasing the hardness from 60 to 40 shore A, the % elongation of the rubber material improves.

6.2 FUTURE SCOPE OF WORK

This particular development is taken up to obtain mechanical characteristics of damping materials. The damping is interlinked with different physical and mechanical properties of rubber compounds. Hence improving any property will have conditional effect on damping and other properties. By using nano particles such as nano silica and nano carbon will improve some of the physical properties and also will affect damping. The improvement of damping along with other properties is to be studied with the inclusion of the same nano particles independently and also in different proportions.

This work can be further extended by using different types and grades of carbon black in improvement of the physical, mechanical, electrical and thermal properties of rubbers.

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