CHAPTER – V

GENERAL DISCUSSION
5.1.0 EXPLOSIVE-BINDER INTERACTION

In any composite system, two discernible component phases are inevitable. An interface region separates them (Figure 5.1). The wet ability of explosive particle with polymeric binder is affected by the energy barrier of two phases. However, a strong bond between binder and explosive is required for PBX performance. One approach to improve binder-filler interaction is the use of surface dresser on the filler through a pretreatment process. The influence of the surface treating agent such as Silane and Titanate on filler dispersion, rheological, mechanical, electrical and magnetic properties has been reported by various investigators (1-5). Surface treatment is meant to help the polymer to wet and disperse the filler. However, the extent of wetting and degree of adhesion are different for each binder-filler and surface modifier combination. The extensive information on various type of coupling agents is available in separate text (6-7). Surface modifiers are generally bi-functional molecules with one end capable of adhering with the filler and other end compatible with the binder. For optimum performance, the appropriate surface modifier for a polymer-filler combination and an effective quantity should be used. The pretreatment techniques can influence the end properties. The two commonly used techniques are continuous process and batch process. The effect of filler-binder coupling on mechanical properties have been demonstrated by Ahegon and Gent (8) and Han et al. (9) Shenoy (10) have reported rheological behavior of various surface treated highly filled system.
All the studies (1-24) indicate that small amount of coupling agents can produce significant improvement in overall performance of composites. The problem of elucidating the role of interface and to discover the major factor involved behind such improvement had been tackled by many different approaches (6,7,14,15). In this context, the formulated theories can be divided into five categories namely: Chemical binding theories, Surface wet ability theories, Deformable layer theories, restrained layer theories, Combination theories.

Since the filler binder interface mechanism are complex, at a time more than one theory are utilized to explain the results. The diversity of chemical and structural differences of the coupling agent inter-phase layer have been investigated by Koenig and
Ishida (11), Boerio (12) and Lipatov (13). Various workers have studied the effects of coupling agent on composite system. It is observed that mechanical properties and cross-link density can be improved by surface treatment. However, the effect of improvement depends on the type of coupling agent. The surface treatment can also retain the performance over a wide range of temperature.

The SEM pictures of phase structures and the interfacial state of AN/PU (16) composite system are shown in Figure (5.2) and (5.2a). (5.2a) is of AN/PU composite without any surface treatment. Picture shows that there is a definite phase between the interface of AN particles and the adhesive, which indicate the poor adhesion of the system. The Figures (5.2a) and (5.2b) show the AN/PU system micrograph processed by different coupling agents. Treated composite sample shows an interface transition layer between the two phases improved dispersion and in agglomerates are also evident from micrograph. It shows that improvement in dispersion and adhesion are directly related to the type of surface modifier.
Figure 5.2

The SEM micrograph of AN+ PU composite system with and without coupling agent treatment. a) AN+PU without dresser, b) AN+PU+A-137silane and c) AN+PU+98 silane. (Taken from, Shiguo et al., reference {16})

Which indicates that surface treatment of explosive particles is an effective mean of improving the overall composite system performance. It is based on the assumption that explosive particle uniform dispersion in polymeric binder will enhance the explosive output as well.
5.1.1 EXPLOSIVE BINDER MIXING

Mixing is an integral part of PBX composition manufacturing. All the PBX production process begins with mixing operation. A continuum of binder and uniform distribution of ingredients are essential requirements for acceptable mechanical and reproducible detonating behavior of the PBX composition. Formation of clusters and agglomerates in PBX composition during mixing can reduce the PBX density due to poor packing. These agglomerates may act as a stress concentration point, which may reduce the mechanical integrity, and can also disturb the uniform explosive properties of the PBX. Therefore, both the types of mixing, dispersive (intensive) and distributive (extensive) are required for uniform explosive composition.

The mixing of high temperature and high pressure sensitive material like explosive with binder require the following for process safety

- Very fine and remote control of parameters.
- Control of ingredient incorporation
- Low temperature and low shear field mixing.

There are large numbers of books (18-20) on filler polymer mixing. In most of the batch and continuous equipment, mixing material is made to flow in multi-direction and passed through various gaps. This way the existing identity of the composition is constantly broken, till a minimum state is achieved. The theory of mixing involves three basic concepts:
1. Increase the area of the interface between the different components.
2. Distributing the element of the interface uniformly through the mix.
3. Balancing the distribution of components to a uniform ratio throughout.

   Besides the use of conventional equipments several other processes are developed for explosive-binder mixing.

5.1.2 RATE AND ORDER OF ADDITION:

   In case of cast able PBXs the quantity of mix is determined by the rate and fashion of ingredient incorporation. Additive can be added directly all together in the beginning or intermittently at a controlled rate in appropriate sequence to the polymer binder. Number of alternative depends on the type, quantity, and physical properties of the ingredient and on the availability of the equipment. Milwaski (21) has demonstrated that by sequential addition of bimodal particle a considerable enhancement in loading density can be achieved. In most cases, it is preferred to add fillers early in the mixing cycle, so that good dispersion is achieved because of the prevailing high viscosity at lower shear rates. The advantage of these techniques is that changes in the formulation (additive package) can be made easily. However, this deprives the processor to formulate most effective proprietary additive package. Usually, plasticizers and the ingredients, which reduce the viscosity, are added later.
However, if plasticizers are added after filler incorporation, they may coat the filler surface and can act as lubricant, which will slow down disperse, and distributive mixing. For this reason, upside down techniques are also used. This is the area where expertise is most needed. Mostly in the case of PBX preparation, inert additive like (wetting agent, cross-linking agent and coupling agent etc) are first mixed with binder and sometimes if necessary with inert or explosive plasticizers. Only after the thorough mixing of additives with binder, oxygen-containing salts of explosives are added.

The uniformity of mix can be examined by torque, microscopic, auto and transmission radiography monitoring. Non-destructive (NDE) techniques like magnetic resonance imagining (MRI) and X-ray fluorescence microscopy (22-23) are also used for composite composition analysis. Torque monitoring usually follows the completion of mixing, macro level uniformity of the composition is indicated by steady torque value. Mervin et al. (24) have used MRI technique for composite propellant consisting of polyalkylene oxide, explosive powder (50%) and Aluminium (15%). Photomicrograph and spin echo image of polyalkylene composite propellant is shown in Fig.5.3. The pointer I, shows in homogeneity of explosive powder distribution in binder and pointer B, point out the existence of entrapped air in the composite material.
5.1.3 RHEOLOGICAL BEHAVIOR:

Knowledge of rheological behavior is useful in all processing step for optimum quality of cast able plastic bonded high explosives. Following rheological characteristics are most desirable for cast able PBXs. It must flow uniformly and rapidly into all parts of die and mould. It must be sufficiently fluid during fabrication to allow the easy escape of gases. It must have sufficient yield stresses so it may not sediment during curing. It
must have minimum effect of temperature and gel structure must not deteriorate by repeated handling.

There is extensive literature on the rheology of filled systems (25-28) including number of comprehensive chapters in number of books. Recently, Shenoy (10) has also reviewed the highly filled systems rheology. The flow properties of the filled systems are primarily influenced by particle shape, percentage and their size distribution.

Hordijk, A.C. et al. (29) have studied the application of the rheological equipment for improved processing of HTPB based PBXs. They have drawn the following conclusion:

Rheological equipment is absolutely needed to study the effect of changes in processing and compositions on cast-ability and pot-life.

More complicated instruments enabling oscillatory measurements give more insight in the cure process and indicate whether result obtained with rotational measurements are valid and to what extent. The complex viscosity, which takes viscoelasticity into account, may be very different from the viscosity incorporating only the viscous part.

The effect of fines on viscosity is that the initial viscosity (end-of-mix) increases and that the viscosity increase with the time is larger as well, resulting in decreased pot-life.

The three ways to prevent settling in a low solid load system worked well. The best results were obtained using 'more fines' and 'by pre-cure'. The method using catalyst and mixing until the viscosity is large enough to prevent settling, needed a higher end-of-mix viscosity than chosen 150 Pa.s for these coarse particles.
Mechanical properties of mono modal PBXs are strongly influenced by the particle size; the smallest sizes give the highest strength and strain. Mechanical properties of bimodal PBXs of 5 micron RDX combined with coarse or very coarse particles in the ratios 70/30 and 33/67 (fine/coarse) are in all cases better than PBXs containing mono modal coarse/very coarse particles.

Unfilled HTPB behaves as a Newtonian fluid. In filling the HTPB pre-polymer pseudo-plastic fluid behavior shows up; the stress to be applied is no longer proportional to shear rate as for a Newtonian fluid (30). A time dependent behavior (thixotropy) and in some cases a yield point (a relative large stress has to be applied before the mix will flow) are measured (31). The extent of these effects increases with increasing solid load.

The addition of an isocyanate starts the chain extension and cross-linking of pre-polymer with a rate, which depends on the type of isocyanate. In some cases a curing catalyst is used.

The rheological behavior of HTPB base plastic bonded explosives (PBX) is similar to the composite propellant. The rheological behaviors of HTPB based composite propellant have been extensively studied (31-35). Figure 5.4 represent the flow behavior of hydroxyl terminated polybutadiene suspension with different shape particle of ammonium perchlorate and Aluminum. The flow behavior is considerably affected by interchange of sphere, flake shaped particle percentage.
Figure 5.4
Viscosity – shear rate curve of HTPB+AP+Al propellant suspension with various volume % of Aluminium (flake and sphere) (taken from Sundberg and Sanden reference 34).
Figure: 5.5

Effect of blend of fine and coarse Ammonium nitrate on viscosity of propellant containing 64% by volume solids and 0.25% weight lecithin, Binder viscosity 20CP. (taken from, Dekker and Zimmerman, reference (35))
The viscosity of HTPB propellant is significantly influenced by flakes and spheres may be acting as ball bearing, which can reduce the internal friction for flow. It further indicates that appropriate ratio of flake and sphere can be used for controlling the flow behavior of the propellant. The effect of bimodal particle size on propellant is shown in Fig 5.5. The minimum viscosity is obtained by using 70% coarse and 30% fine Ammonium nitrate particles. It may be due to tight packing, which effectively reduces the surface area of the particles in the system, this offer less internal resistance to flow. The study indicates that a mixture of correct particle size is essential for high density as well as for easy processing of the PBXs.

5.1.4 SHAPING AND CASTING OPERATION:

The PBX can be casted by methods similar to those established for casting rocket propellants. The hazards associated with handling dry RDX / HMX are minimized by coating them with 2-3% desensitizer by slurry method before drying to less than 0.5% moisture level essential for processing with isocynates (36)

5.1.5 CURING

Plastic bonded explosives after completion of mixing and shaping operation are usually cured at ambient temperature and in some cases at elevated temperature. The performance of cross-linkable composition depend on cross-link distribution and its, percentage. In these, highly explosive filled systems, the presence of large amount of ingredients such as oxygen and fuel, etc. can interfere the cross-linking reaction and often activate the unwanted side reaction. Therefore, knowledge of curing mechanism and parameter are important for PBX solidification.
Curing can be accomplished by physical and chemical methods (37-42). However, physical method has very limited use. The chemical methods are commonly used chemical cross-linking of binder in PBX; permit greater flexibility over mechanical properties.

The standard routes (43) for network structure formation in polymeric system are known and it usually follows the oxidative condensation reaction with minor amount of side products. The temperature and duration of reactions depends on binder composition charge dimension and on cross-link density and its distribution. The rate and temperature of the reaction can be manipulated partly by suitable catalyst. The type of catalyst, number of steps required for completion of reaction and operating parameter depend on the system. For example, unsaturated polyester styrene based composition are cured at ambient temperature in 24 hours and in three steps; acrylate base composition are cured at room temperature in two steps and at different rates depending on the availability of oxygen polysulphide and butadiene styrene based composition are cured in one step at 160°F and 200°F respectively.

Polyurethane formulation can be cured at ambient temperature by using suitable catalyst.

5.1.6 CURING PARAMETER

Time and temperature are the most important parameter for curing reaction. An uncontrolled reaction can cause a rapid exotherm and uneven temperature distribution, which may generate the cracks in the grain.
Therefore, a controlled and uniform temperature distribution is essential for reducing voids, shrink strain and overheating of the PBX mass. Several theories are developed for cure parameter optimization. Diffusion theory (37) suggests that cure times are proportional to square of the grain diameter. A prolonged heating at cure temperature can deteriorate the properties, completeness of curing is best monitored by hardness. A system is considered as cured; when there is no further change in mechanical and explosives properties can occur at cure temperature.

For kinetic study physical properties like viscosity, density, hardness, dielectric constant or electrical conductivity together with spectroscopy (IR) is monitored at regular interval of times or continuously (44-45). The differential scanning calorimeter (46-48) is used for quantitative estimation of cure parameter. Curing can also be accomplished by radiation energy (48-49) and dielectric heating (50-51). The rapid vibration of dipole under the influence of alternating electric field can generate sufficient heat for curing. Similarly, the high radiation can create the radical for network formation.

5.2 MECHANICAL PROPERTIES

5.2.1 STRESS-STRAIN BEHAVIOR

Plastic bonded explosives are subjected to various types and kind of applied stresses such as impact shocks, vibrational strains and multi-axial stresses (i.e. extra internal pressure at firing) in their service performance. It is expected that these PBX
must not creep during storage, must not crack or deform excessively accelerating flight condition and must retain adequate elongation over wide range of temperature and strain rates. These highly explosive filled systems consist of large number of interfaces, and exhibit non-uniform straining in the vicinity of explosive crystals. Therefore, they are introduced by binder explosive interaction to a greater extent than conventional low loaded system. The important mechanical properties like strength, elongation, modules and toughness of the systems are commonly determined by their stress-strain characteristics. Stress-strain behaviors of polymer based composite material are reported by various workers (53-61). It can be represented by statistical and phenomenological theory of rubber elasticity (61-67). The statistical theory of rubber elasticity (61-62, 66) describe stress-strain behavior as

\[ \sigma = NKT \left( \alpha^{-1}/\alpha^2 \right) \] ..........................(1)

Where,

\[ \sigma = \text{stress}. \]

\[ N = \text{Number of effective network chain (or segments) per unit volume} \]

\[ \alpha = \text{Extension ratio} \]

\[ K = \text{Boltzman constant.} \]

\[ T = \text{Absolute temperature in Kelvin.} \]

Equation (1) indicates the non-linearity of stress-strain and proportionality of stress with temperature.

The popular Mooney equation (62-66) describe the stress-strain behavior by the following expression:

\[ \sigma = 2C_1 \left( \alpha^{-1}/\alpha^2 \right) + 2C_2 \left( \alpha^{-1}/\alpha^2 \right) \] ..........................(2)
Or \[ \sigma / 2 (\alpha - 1 / \alpha^2) = C_1 + C_2 / \alpha \] ........................(3)

Where,

\[ C_1, C_2 = \text{Empirical constants.} \]

\( \sigma \) is stress and \( \alpha \) is Elongation ratio.

The equation suggest that a plot of \( \sigma / 2 (\alpha - 1 / \alpha^2) \) against \( 1 / \alpha \) yield a strength line of slope \( C_2 \) and intercept \( C_1 + C_2 \) on the axis \( 1/\alpha =1 \).

The formula contains two term of which first is the same as that derived from statistical theory where \( 2 C_1 = NKT \), while second involves constant \( C_2 \) which represents the deviation of Mooney theory both the relation are useful for prediction of initial portion of PBX stress-strain curve. For complete prediction more generalized modals are required.

A gradual decreasing slope followed by plateau diminishing stress region before rupture are typical features of polymer based composite material Saylak (54) and Goemez et al. (68) have studied the stress-strain behavior of polyurethane and HTPB based composite materials. The data shows strong influence of explosive loading and temperature on stress-strain characteristics of composite materials. The behavior can be explained by dewetting phenomenon. Dewetting phenomenon in polymer based composite material have been extensively studied (56-57) by microscope. The changes in volume as a function strain in explosive filled plasticized system have been studied (55,58,69) by various techniques. Kruse (70) and Fishman and Rinde (71) have studied the variation of Poisson's ratio in polymer composite system. Chi (72) has reported the tensile data of polyurethane (polyether, polyester pre-polymer) based composite system with
HMX, AP particles and plasticizers. The data shows increasing trend of tensile strength and elongation with explosive volume fraction. Simultaneous increase in tensile strength and elongation are not common. However, it is dependent on system composition and can be explained by 'stationary stress' theory (73) and 'pseudo cross-link concept' (64,65). Stationary stress theory explains that high strength of polymer composite material may be due to dissipation of applied energy in large number of internal cracks around the explosive particles, and due to the propagation of cracks by 'slip stick' and 'knot' formation mechanism. Pseudo cross-link concept explains that reinforcement of polymer composite system may be due to the formation of complexes in the system. Complex formations in polyethylene oxide (PEG) with many inorganic salts are well known (74-75). These complexes of localized interaction act as reinforcing agent in polymer composite system. On the basis of stationary-stress theory high relative elongation for HMX filled plasticized system may be due to formation of micro cracks around the explosive particles, which can inhibit the crack propagation thus can increase the strain capability. HMX composite results are consistent with stationary stress theory and AP composite results are consistent with pseudo cross-link concept.

The modulus of polymer composite system is most affected by explosive percentage. There are number of equations (76-83) which relate modulus of composite material with filler volume fraction. Einstein (79) has proposed a relation considering non-solvated rigid spherical particles, for the case of perfect adhesion and no adhesion between filler matrix material. The popular Guth-
Gold equation (80) relates the modulus value by following expression.

\[ \frac{E}{E_0} = 1 + 2.54 + 1.41 \varphi^2 \] ........................ (4)

Where,

\[ E \text{ and } E_0 = \text{moduli of filled and unfilled binder.} \]
\[ \varphi = \text{volume fraction of the filler.} \]

Eillers and Van Dycho have proposed (76) another equation, which involves the packing fraction factor of the filler for modulus prediction as:

\[ E = E_0 \left[ 1 + 1.25 \frac{\varphi}{1 - \varphi / \varphi_p} \right]^2 \] ........................ (5)

Where,

\[ \varphi_p = \text{packing fraction of the filler particles.} \]

Packing fraction of fillers mainly depends on its particle size distribution. Equation (5) suggest that modulus of composite material depends on packing fraction, volume fraction and binder modulus.

Polymer composite system moduli have been studied by Chi (72) Geomez et al. (68). Chi (72) has studied the polyurethane system based composite system of HMX and AP particles. The binder system is based on PEG and PGA pre-polymer composition. The data indicate that reinforcement not only depend on particle type but also depend on pre-polymer component of the binder. Different levels of reinforcement are obtained for AP and HMX particle for PGA and PEG pre-polymer-based binder. Figure 5.6 shows the increasing trend of relative modulus with explosive volume fraction, which depends on the type of explosive particles and binder pre-polymer.
Figure 5.6

Effect of HMX and AP on modulus of polyurethane PBX (PEG and PGA base) for different plasticizer to binder, PI/Po. △-PEG+HMX, PI/PO= 2.33, X = PEG+AP, PI/PO=2.33, □PGA+AP, PI/PO= 2.33, O= PEG+HMX+NC, Pi/Po=2.50, Guth-Gold equation (taken from chi, reference [82])
Goemez et al. (68) have studied the effect of bimodal type explosive particles on HTPB binder based composite system. The data indicate the increasing trend of modulus with explosive volume fraction as well as the strong influence of bimodal particle size (i.e. coarse to fine ratio) of Ammonium perchlorate and Aluminum powders for HTPB propellant.

5.2.2 ULTRASONIC MEASUREMENTS:

Modulus of the polymer based composite system can also be determined by ultrasonic measurements (84-87). Ultrasonic technique essentially estimates physical arrangement of explosive particle inside the polymeric binder and intrinsic stiffness of the PBX. The technique utilized the sonic transmission pulses for measurements and test can be performed at various temperatures and frequencies. As per classical mechanics, sonic modulus can be expressed as

\[ C_u = \sqrt{\frac{E_0}{\delta}} \]

Where,

- \( E_0 \) = Sonic modulus.
- \( C_u \) = Ultrasonic sound velocity.
- \( \delta \) = Density of the system.

It has been noted that polymer composite system exhibit low modulus values (88) in comparison to other composite system because of the high loading.

It may be attributed to the dominant permanent deformation of the systems and weak explosive binder interaction. However, both the effects are rate as well as magnitude dependent. Based on the studies polymer composite system can also be
classified as non-elastic composition. Since very limited information is available, it is difficult to conclude further.

5.2.3 EFFECT OF TEMPERATURE:

PBXs are expected to perform over extended range of temperature. The variation of mechanical properties of PBX with temperature mainly depends on the type of binder. Elongation is the most effected property of polymer composite system by temperature. Rests of the mechanical properties of polymer composite systems either drops or remain unaffected in limited range of temperature. De Fries and Godfrey (89) have reported the variation of mechanical properties of the PVC based composite over a wide range of temperature -60° F to 300° F. The data indicate decreasing trend of Young's modulus, ultimate stress and yield stresses with temperature. However, elongation of the system reaches a sharp maxima of around 200° F and then drops. Mastrolia and Klager (91) have reported the stable mechanical properties of carboxyl-terminated polybutadiene composite system over a wide range of temperature range, but the elongation of the system varies with the temperature, curing agent and plasticizer.

5.2.4 IMPACT PROPERTIES:

PBXs are subjected to impact loading during their service life and have to survive during rough handling and often in regress environment. The ability to withstand shocks can be used as quick deciding factor for PBX acceptability and grading.

A PBX may have attractive mechanical properties such as good stiffness, etc. still may not be acceptable if it is not tough enough to withstand the strains encountered in actual uses.
Therefore, it is important to analyze PBX at high strain as well. There is very limited information available (91-94) in this area. Dagly et al. (91) have studied the high strain mechanical behavior and ignition sensitivity of RDX / EVA (95:5) PBX.

Different molecular weights and vinyl acetate content, ethyl vinyl acetate content, copolymer composition were molded and compacted. The PBX samples of high vinyl acetate content and high molecular weight copolymer exhibit high strain capability and least impact sensitivity. An increase in binder percentage decreases the impact sensitivity and changes mode of failure from brittle to ductile fracture. The shock sensitivity of the compacted composition decreases with increasing vinyl acetate content and decreases molecular weight of copolymer. The results are mainly attributed to explosive binder interaction capability. The study under that binder characteristic can have marked influence on PBX performance.

The brittle temperature of PBX determines its low temperature application limit. Brittle temperature of copolymer composite system has been studied by Ning (92). As expected, it varies with type of binder and plasticizer.

5.2.5 FRACTURE BEHAVIOR

Analysis of causes for polymer composite system failure is useful, so that the preventive measure can be taken at early stages of formulation.

A failure criterion is a generalized physical situation at which composite system may disintegrate. A strain energy criterion measure of crack extension and is commonly used for fracture behavior analysis (95-96). It has been noted that strain energy
criteria can provide a better estimate of PBX performance than simple stress-strain behavior. Tod et al. (97) have studied hysteresis characteristic of polymer composite system. It has been noted that in case of elastomeric and thermoplastic-elastomer based polymer composite system, principal mechanism involved for energy dissipation are interface debonding and micro void formation. Polymer composite system also exhibits inelastic behavior and strain hardening characteristic. PBX's inelastic behavior may be due to their high percentage content of rigid particles. Strain hardening characteristic mainly depend on type of binder and take place at stress level greater than yield stress of the composition.

5.3 MULTIAXIAL STRESS STABILITY

In polymer composite system internal gas pressures are generated during ignition, which produces an extra strain in the system, and if it exceeds beyond certain limit, it may damage the system, polymer composite system should be tested under super-imposed pressure condition. Surland et al (98) and Vermon (99) have described a device, which can be used for studying the polymer composite system response in tri-axial stress field. Traissac et al. (100) have reported the mechanical behavior HTPB based polymer composite system at several super-imposed condition strain, hydrostatic pressure and temperature.

Pressure significantly reduces the failure strain energy of the polymer composite system. It is dependent on the binder system and it has been noted that strain energies are proportional to the modulus of the binder.
Frarris (101) and Peng (102) have reported stress-strain dilatation in polymer composite system. Highly explosive filled composite exhibits dilatation by biaxial large deformation and at various temperatures. The dilatation in polymer composite system may occur due to formation and growth of vacuoles in the vicinity of explosive filler. Numbers of models (98-103) have been proposed to represent this non-linear visco-elastic behavior, which can be used for polymer composite system microscopic failure predication.

5.4 DYNAMIC PERFORMANCE

In field PBX composition are exposed to dynamic stress-strain condition. Under such dynamic condition, the explosive composition exhibit entirely different behavior compared to static state. Studies pertaining to:

1. Vibration.
2. Shock waves attenuation.
3. Cyclic fatigues are useful for PBX composition design and development.

Therefore, it is important to examine these materials under such simulating condition. Visco-elastic characteristics of the material can be investigated by force, free and resonant vibration (104). For polymer composite system in most instances loading are applied in regular sinusoidal fashion. Non-sinusoidal studies are rarely performed. However frequency response of sinusoidal stress-strain the viscous and elastic part of the system analyzed. The relationship governing the dynamic behaviors of linear visco-elastic materials are discussed in several texts (104-106).
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