4-2003

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Recommended Citation

Karnakote, Sachitanand, "Influence of Infrared Absorbing Anions on Paper Coating Structure" (2003). *Masters Theses*. 4952.
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INFLUENCE OF INFRARED ABSORBING ANIONS ON PAPER COATING STRUCTURE

by

Sachitanand Karnakote

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Paper and Printing Science and Engineering

Western Michigan University
Kalamazoo, Michigan
April 2003

ACKNOWLEDGMENTS

I wish to express my appreciation to all those who have assisted me in last two years. I am particularly grateful to US Borax who have funded the research and provided me with samples. I wish to thank Dr. Thomas Joyce for his guidance and encouragement throughout the research. I also thank Dr. Margaret Joyce and Dr. Dan Fleming for their valuable suggestions and support.

Sachitanand Karnakote

INFLUENCE OF INFRARED ABSORBING ANIONS ON THE PAPER COATING STRUCTURE

Sachitanand Karnakote, M.S.

Western Michigan University, 2003

Infrared units are widely used in paper coating drying to initiate evaporation and quickly reach solids immobilization point. Thermal efficiency of IR units can be improved by increasing absorption of coating color. Borate compounds have shown good IR absorption at wavelengths typical to commercial IR units.

The objective of this research was to evaluate the compatibility of selected borate-containing compounds with the primary components of the paper coatings like clays, carbonates, and some binders.

Coatings were prepared at 60% solids and viscosity and pH were adjusted to 900-1200 cp and 8.5-9.5 respectively. Dynamic stress and frequency sweeps were carried out using Rheometrics 5000. High shear measurements were done using Hercules high shear viscometer.

The borate compounds were found to interact with the coating components. The interactions of borates differed with pigment and binder type. There was a marginal increase in pH and viscosity with concentration of borate in the coating color. The strength and amount of interaction increased with the concentration of borate in the system. At borate concentrations < 1% (by weight), interactions are weak and do not adversely impact with the rheological properties at high shear.

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CHAPTER I

INTRODUCTION

The desire for higher quality graphics on printed-paper products places a great demand on the printer and coated paper supplier. Six to eight color printing is becoming more common. Additional print stations and increased press speeds continue to challenge the printer and paper supplier. The printer must be able to print faster, and the paper supplier must now be concerned with supplying a product capable of withstanding the additional stresses of higher press speeds and more colors. Product uniformity is key to both the printer and paper supplier.

The uniformity, definition, and "snap" of a printed image depend on the characteristics of the base sheet, paper coating, ink, and their interactions[1]. As the demand for printed products grows, the demand for faster paper coaters and printing presses also grows. To meet these challenges, papermakers and printers continue to search for new technologies that will enable them to run faster and better. Although new presses and coaters are available to meet these demands, the high capital cost associated with such equipment and the fear of investing in technology that is rapidly changing have resulted in manufacturers seeking new technologies to improve their current processes and make the paper and printing of good quality less expensive. Low cost, chemical-based solutions to improve productivity and smaller scale process modifications are constantly being evaluated.

The "bottleneck" operation of any coated papermaking process is the drying process[2]. The drying process is the most energy intensive operation in any mill or web-fed pressroom. The improper drying of any coated product could be disastrous to the quality of the finished product. Coating and print mottle are known to be related to the improper drying of the substrate. Blistering, back trap mottle, ink smudging, rub resistance, and poor gloss have shown to be related to the method of drying[3].

To alleviate some of these drying problems and increase drying efficiency, manufacturers have installed infrared drying units on their presses and coating operations. In coated paper and paperboard operations, infrared dryers are commonly installed just prior to the first drying unit to help set the coating and prevent migration of the coating into the base paper. Migration is also known to cause coating mottle and poor z-direction coating strength. Coating mottle is known to cause print mottle and reduce the uniformity of the printed image[4]. Press manufacturers are installing infrared dryers on web fed presses to help set and dry the inks faster so that higher press speeds can be achieved. Web fed offset and water-based flexographic printing inks are more difficult to dry than solvent-based inks.

One of the ways of improving the speed of drying while using infrared dryers is the use of IR absorbing anions in the coating structures and/or in inks. If an IR absorbing anion is used in a paper coating, the anion will absorb the IR light when passed through the dryers and the paper coating will heat up and dry quickly. Thus, it is important to study the compatibility of the IR absorbing anions with the coating structure, i.e., with the commonly used pigments, binders, thickeners, dispersants, etc., so that the proper anion can be used as an additive in the coating formulation. Compatibility can be studied by analyzing the rheology of the mixture resulting when anions and the coating formulation components are combined.

CHAPTER II

LITERATURE REVIEW

Infrared energy

Thermal radiation is the transfer of heat by electromagnetic waves caused by temperature differences between two separate bodies in a low-density medium (such as air) or vacuum[5]. Thermal radiation encompasses a small wavelength range between 0.1 and 100 μm in the overall electromagnetic spectrum (see Figure.1.). Thermal radiation includes the familiar UV, visible, and infrared regions. The infrared region (IR) is in the wavelength range from 0.75 μm to 100 μm. It is usually divided into short-wave IR (0.75 to 2 μm), medium wave IR (2 to 4 μm), and long-wave IR (4 to 100 μm) (1, 2). Commercial infrared equipment usually generates short or medium wave IR.

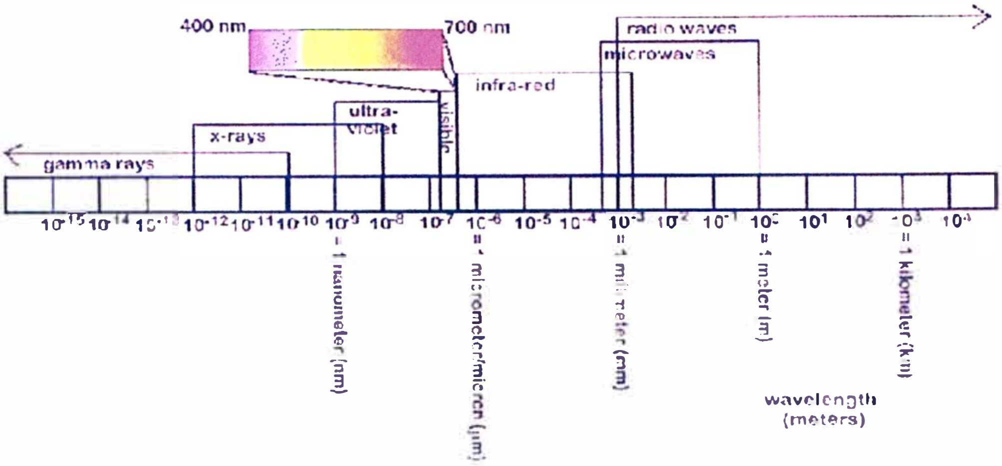

Fig.1. Electromagnetic Spectrum of Light.

Atoms are made up of positively and negatively charged particles. Each of these particles has a magnetic field around itself. Atomic vibrations disturb the magnetic fields around the particles. This disturbance in the field generates electromagnetic waves.

Infrared heating

Every material absorbs IR waves when exposed to them. The proportion of the incident energy absorbed varies depending on (a) the wavelength of IR to which the material is exposed, (b) the surface finish of the material, and (c) the thickness of the material. For example, a rough oxidized sheet of steel may absorb less than 20% of the incident energy, reflecting the remaining. However, a sheet of glass will transmit short-wave IR, but will absorb medium and long-wave IR. A sheet of 350 g/m^2 (60 lb) linerboard will absorb a greater proportion of IR than a thinner sheet of 125 g/m^2 (26 lb) corrugating medium[6].

Electromagnetic waves generated by a high temperature object travel through air and at some point strike a cool object. When this happens, the vibrational forces created by the waves excite the atoms of the cool object. This action causes the cooler atoms to vibrate more intensely. As the atoms vibrate more intensely, the temperature of the atoms increases. In this way, electromagnetic energy is transformed into heat energy.

IR dryers achieve heat transfer by radiation as opposed to steam cylinders (conduction) or hot air systems (convection). Since no medium is required to transfer heat energy, the factors that affect radiation heat transfer are emissivity, the view (or shape) factor, temperature, and wavelength of the IR energy. Inherent advantages of non-contact IR drying are high heat transfer rate, two-sided drying, and reduced picking and binder migration.

Electromagnetic waves striking an object are absorbed, reflected, or transmitted through the object (as shown in the Fig. 2, below). The measure of a material's ability to absorb electromagnetic energy is called emissivity. Thus, if a material reflects 30% of the electromagnetic energy striking it, and absorbs the other 70%, its emissivity is 70%, or 0.7.

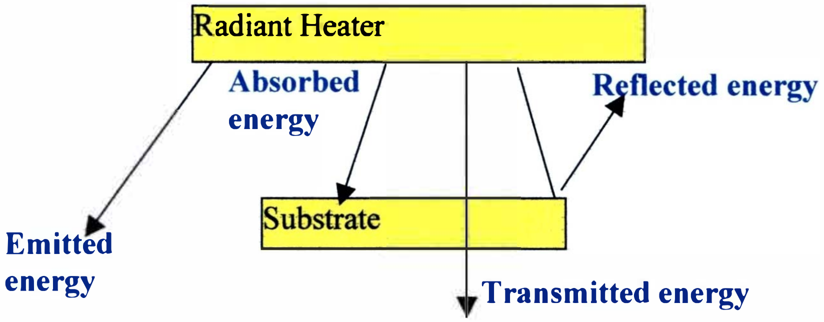

Fig.2. Reaction of a substrate to the emitted light energy.

The emissivity value also indicates how well the material can emit or radiate energy. A material with an emissivity value of 0.7 radiates only 70% of the energy that a perfect black body radiator at the same temperature could radiate. A perfect radiator has an emissivity value of 1.0; thus, materials with a higher emissivity value absorb and emit more radiation. Materials that absorb more energy heat up faster, and, consequently, dry faster. The emissivity of a mixture of materials is the linear addition of emissivity spectrums of all the materials in the mixture.

Rheology and rheometry

Rheology is the study of the deformation and flow of materials. It is a material property, which is critical to the performance characteristics of processed materials. Rheological measurements involve the use of a precision actuator to apply to a sample (liquid, melt, soft solid, rigid solid) a slight, oscillatory, deforming strain, and, using a sensitive transducer, measure and record the resultant stresses generated within the sample[7].

Materials respond to the applied strain or stress by dissipating energy in the form of heat (viscous dissipation), storing the energy elastically, or through a combination of these two mechanisms. Most materials show some characteristics of both elastic and viscous behavior, and are therefore called viscoelastic. To characterize such materials accurately, both types of response—elastic and viscous—must be measured.

Dynamic mechanical testing makes it possible to measure both of these properties. Dynamic mechanical analysis can be used to analyze both elastic and viscous material response simultaneously. In this type of test, an induction motor is used to apply a sinusoidal strain to a material (either in tension, bending, or shear) and the resulting stress is measured with a force-measuring transducer. The force is then electronically separated into two components—an elastic stress and a viscous stress. The elastic stress of the material is the component of the measured stress that is in phase with the applied strain, and the viscous stress is the component of the stress that is in phase with the strain rate, or 90° out of phase with the strain. Thus, both the strain amplitude and strain rate dependence can be measured, giving information on both the elastic and viscous properties of materials.

Several quantities can be calculated from the measured strains and stresses. If the test is done the shear mode, then shear moduli (G) are calculated. Tensile and bending tests measure tensile moduli (E). The elastic modulus (G' or E') of a material is defined as the ratio of the elastic (in-phase) stress to strain and relates to the material's ability to store energy elastically. Similarly, the loss modulus (G" or E") of a material is the ratio of the viscous (out of phase) component to the strain, and is related to the material's ability to dissipate stress through heat. The ratio of these moduli (G"/G' or E"/E') is defined as tan δ, and indicates the relative degree of viscous to elastic dissipation, or damping, of the material.

A variety of test geometries are used in rheological testing. Solids are tested in shear, tension, and bending using rectangular or cylindrical samples. The properties of fluids are measured using parallel plate, cone and plate, or couette (concentric cylinders) fixtures. The fixture used to test a material depends on several factors, including the material’s stiffness, viscosity, instrument sensitivity, and type of measurement. Testing is generally nondestructive and sample sizes are usually small.

Rheometers control three parameters in any given test: frequency of oscillation, amplitude of oscillation, and test temperature. A typical test holds two of these parameters constant while varying the third. In a frequency sweep (a sweep is a continuous variation of a parameter), the test frequency is varied to establish the time dependence of a material, with frequency being inversely related to time. One example of such dependence is thixotropy, or the change in viscosity or elasticity as a function of frequency.

Strain sweeps are used to measure the range of linear viscoelastic behavior of materials. The shear modulus of a material is independent of strain amplitude up to a given applied strain. Within such a range, they are said to be linearly viscoelastic. Beyond that point the structure of the material begins to break down and the elastic modulus drops.

Temperature sweeps are useful for measuring the properties of solid materials. Impact properties, degree of crystallinity, and other morphological properties are studied in this way. Phase transitions can be detected and analyzed to locate components in polymer blends.

Dynamic mechanical analysis is a sensitive method of exploring both the molecular properties and process ability of many materials. It enables characterization of the structural differences between materials that can be used to determine the degree and strength of interaction between components. It also provides information about how the materials will perform under different processing conditions, i.e., pumping, mixing, extruding, application, and metering. Such information is important for both formulation development and process design and optimization.

Coating rheology

Coating rheology plays an important role in establishing criteria for processability, runnability, and coated paper properties. Experience has shown that if rheology is controlled within certain limits the coating process is under control and a quality-coated paper is produced. The ability to understand and optimize the coating process and the final product performance depend greatly on rheological concepts. Appropriate rheology is required for acceptable coater runnability and consolidation of the coating structure. This applies not only for the metering step, where excess coating is being removed and a thin film is deposited onto the moving web, but also for the entire coating process, including coating preparation, pumping, screening, coating transfer onto the web, flow into the metering nip, leveling after metering, and drying.

Selection of IR-absorbing compounds

IR radiant energy falling in the 1 to 8 micron range is of primary interest. This is due to the high level of absorption of radiant energy into both the paper and coating in this range as shown in the following figure, Fig.3.

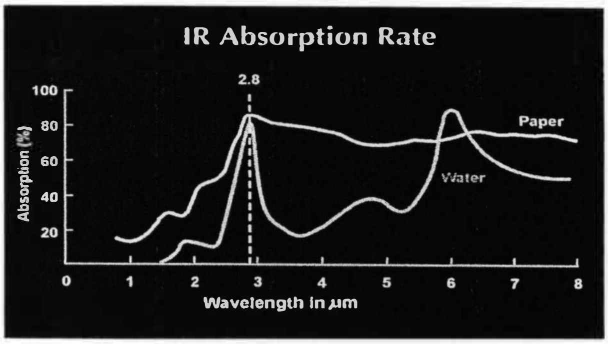

Fig.3. Abosorption of IR energy by paper and water.

Polyatomic ions exhibit characteristic infrared spectra[8]. It is important when selecting these ions for application in paper coatings that they exhibit a strong absorption characteristic in the short and medium IR band, where water and paper are known to absorb. Based on this understanding borate compounds were selected.

The ability of borates to absorb infrared energy offers the possibility of their use in coating and printing applications to improve the emissivity, and, consequently, the IR drying efficiency of coated substrates and printed products. Borates are FDA approved; thus, their application in these products would readily be accepted. The ability to improve the IR drying efficiency of coated and printed products could result in lower drying costs and/or increased productivity. It may also increase the interest in the use of IR dryers by other industries. If the concept were proven to be technologically feasible, it would be of great interest to the producers of IR dryers and the U.S. Department of Energy.

Borates are potentially good additives for coating formulations as they can act as cross linkers, flame retardants, bulking agents, and can increase ink receptivity (which is an area of future studies with these substances in coatings if they are compatible with other coating components commonly used). The borate containing components selected for use were sodium tetraborate pentahydrate (Neobor), disodium octaborate tetrahydrate (Polybor), and sodium tetraborate decahydrate (Borax). Three different borates were selected to determine the difference of interactions with the difference in structure and degree of hydration.

CHAPTER III

STATEMENT OF PROBLEM AND OBJECTIVE

Drying is considered to be the bottleneck operation in any paper mill or a printing unit. Infrared dryers are being installed to get the best results for drying; they provide a better control and also help increase the speed of the paper coater. Still, due to the limitations of speed due to drying, it is important to address issues that help in increasing the speed of drying, and hence decrease the overall production cost, which increases due to drying.

The objectives of this research are

1. To measure, using rheological methods, the interactions of IR – absorbing anions with coating components, and,
2. To evaluate the compatibility of IR-absorbing anions with paper coating components.

CHAPTER IV

EXPERIMENTAL PLAN

The experimental plan was divided into three phases. In Phase I the interactions of borates with the pigments were studied. Phase II examined the interactions of borates with binders. Coating systems containing pigments (clay and carbonate), binders (PVA and SBR) and borates were prepared and different measurements were made. In Phase III, coatings containing pigment, binder, thickener and borates were prepared and the interactions were studied. The following charts describe the experimental plan.

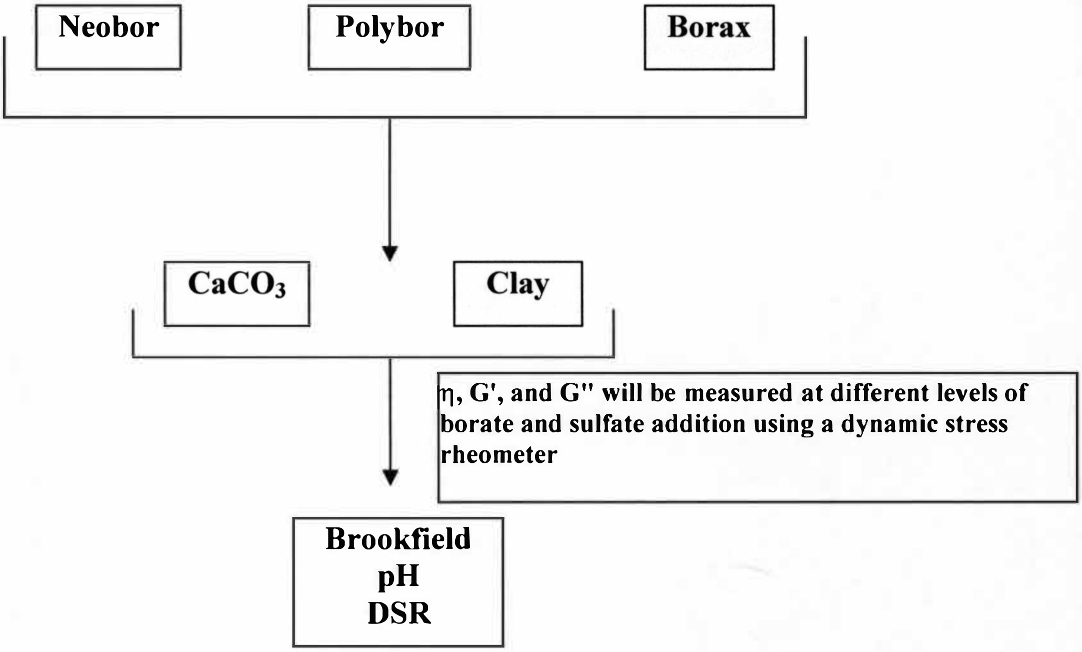

Fig.4. Phase I of the experimental plan.

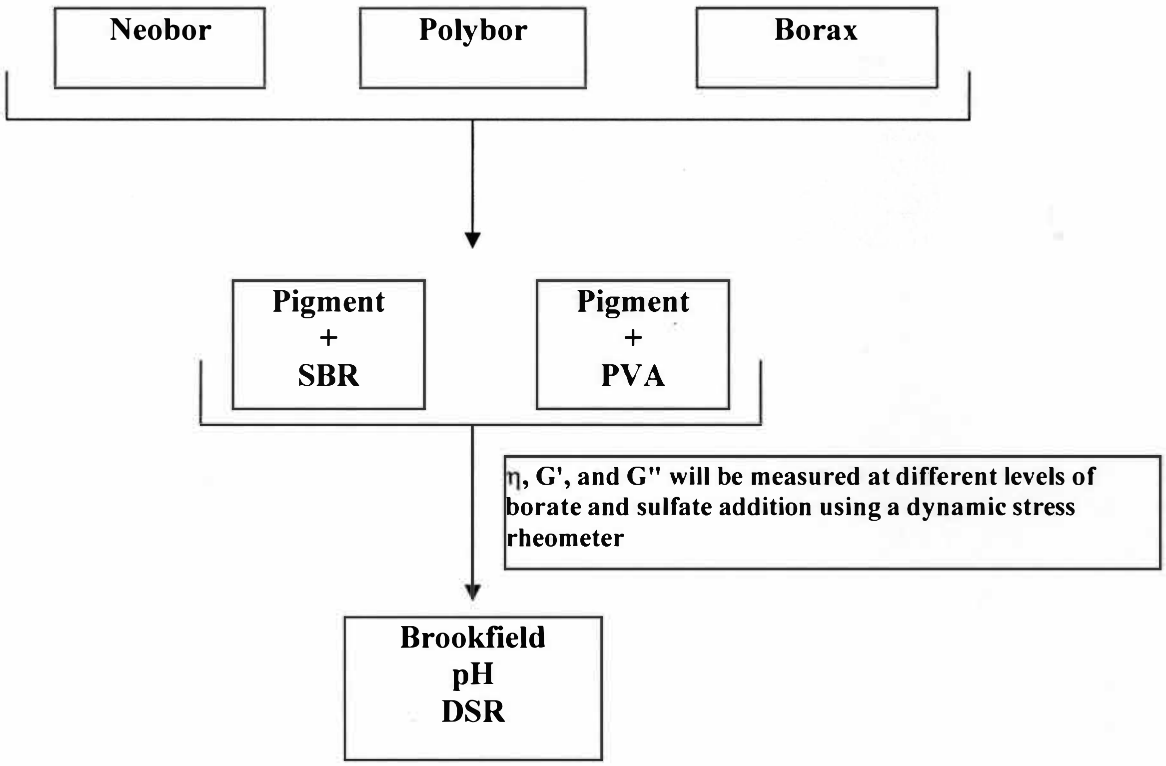

Fig.5. Phase II of the experimental plan.

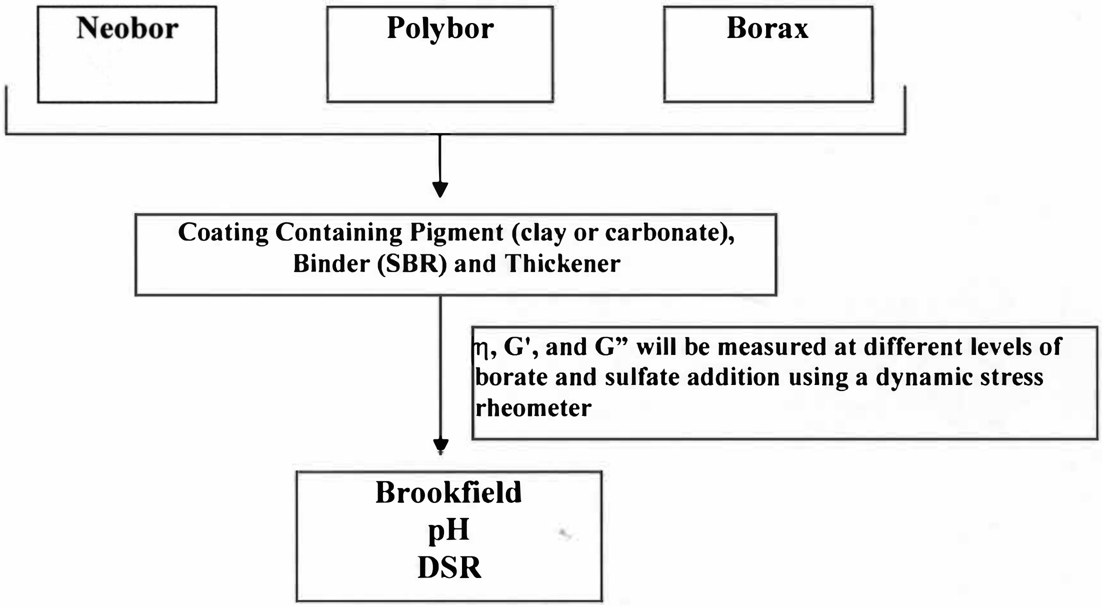

Fig.6. Phase III of the experimental plan.

Preparation of coatings

The coatings were prepared using several levels of addition of several borate products. The interactions of borates with clay and carbonate pigments, binders (styrene butadiene, polyvinyl acetate), and an alkali swellable thickener (Alcogum) were examined.

Borate and pigment slurries

Pigment slurries were prepared by dispersing the pigments into the borate solutions at different borate concentrations. The borate solutions were prepared by adding the dry borate into water under agitation. At the higher concentrations of borate, the solutions had to be heated to 70 °C to solubilize the borate particles. The solutions were then cooled to room temperature and allowed to sit overnight to assure that they were stable and did not precipitate. The solubility limits of each borate product (Borax technical granular, Neobor, Polybor) were determined this way. The concentrations of borates ranged from 0 – 7 % on the weight of the water added. The total percentages of solids of the slurries ranged from 33 to 45%.

Borate and binder coatings

Coatings containing pigments, binders, and borates were prepared at 60% solids. The clay and carbonate pigments were added to 70 % solids, styrene butadiene (SBR) to 50 % solids, and polyvinyl acetate (PVA) to 47 % solids. The pigment to binder ratio was fixed at 10:1. The concentration of borates ranged from 0 – 4 % on the weight of the total water added. In these experiments, the concentration of the borates was kept low to avoid precipitation at low temperatures. The order of addition was maintained as pigment slurry, borate, water, and binder, respectively; all additions were made under shear.

Borate and thickener coatings

To determine the reactivity of the borates with an alkali swellable thickener, Alcogum coatings were prepared with pigments, binder (SBR), thickener, and borates. The coating was prepared at 60 % solids. The solids concentration of pigments, borates, and binder was taken as before. One part of thickener at 30 % solids was taken. The pigment to binder ratio was fixed at 10:1. As the thickener had a low pH, when it was added to the coating, it lowered the pH of the coating. To increase the pH, 8 % KOH solution was added. The order of addition was maintained as pigment slurry, borate, water, binder, thickener, and KOH solution, respectively; all the additions were made under shear.

The borates were obtained from US Borax, the SBR from Dow chemicals, PVA and Alcogum from Rohm and Haas.

	Borax	Neobor	Polybor
HC	X	X	X
HG	X	X	X
HC+SBR	X	X	X
HC+SBR+ALCOGUM	X	X	X
HC+PVA	X	X	X
HG+SBR	X	X	X
HG+SBR+ALCOGUM	X	X	X
HG+PVA	X	X	X

Table.1. Different coating systems.

Measurements

The viscosities of the mixtures were measured using a Brookfield RVT viscometer at 22 °C using a No. 3 spindle at 20 rpm. The rheological properties of the coatings were measured to determine the influence of borates on wet coating structure. Dynamic rheological measurements were performed using a Dynamic Stress Rheometer.

Dynamic Stress Sweep (DSS), Frequency Stress Sweep (FSS), and Steady Stress Sweep (SSS) tests were performed on the slurries. These tests were performed at 25 °C. A double couette geometry (inside cup diameter = 40 mm, inside bob diameter = 38 mm, outside bob diameter = 42 mm, outside cup diameter = 44 mm, bob length = 50 mm) was used for all these tests. The DSS was performed at a frequency of 1. The FSS was performed at a stress in the linear region just before the critical stress value obtained from the DSS, and the frequency range for the FSS was 0.1 - 100. The Hercules was run at 25 °C using the E bob with an input density of 0.960 g/cm^3; it was run at a maximum RPM of 6800 for a ramp time of 20.4 seconds.

The above measurements with viscometer, pH meter, and rheometer were performed on all the coatings prepared. Some of the coatings were also tested for high shear behavior using a Hercules High Shear Viscometer.

CHAPTER V

RESULTS AND DISCUSSIONS

The main focus of this research was to find the compatibility of borates with commonly used coating components, i.e., how the borates interact with the coating components, and whether the interactions interfere with the runnability of the coating.

It is important that prior to using borates as infrared-absorbing anions to increase the drying efficiency of infrared dryers to determine if the borates hinder or interact adversely with the functions of the major coating color components. So, it is necessary to study simple, model coatings with borates in them.

There are no published data on the interactions of borate components with coating components such as clay and calcium carbonate. Hence, this study is the first of its nature, and these results cannot be compared with any earlier results. The rheological data obtained from experiments performed (with and without borates) on a Brookfield Viscometer, Dynamic Stress Rheometer, and Hercules Viscometer are compared and discussed.

Figures 7 and 8 demonstrate the interactions of basic coating components without the borates. The addition of thickener, alcogum, increased the G′ of the clay coatings to the value found for the carbonate coating. The addition of thickener appears to strengthen the interactions in the clay coatings. This is shown by the higher yield stress in Figure 8 for the clay, SBR, Alcogum coating in comparison to Figure 7.

Rheological characterization of control coatings

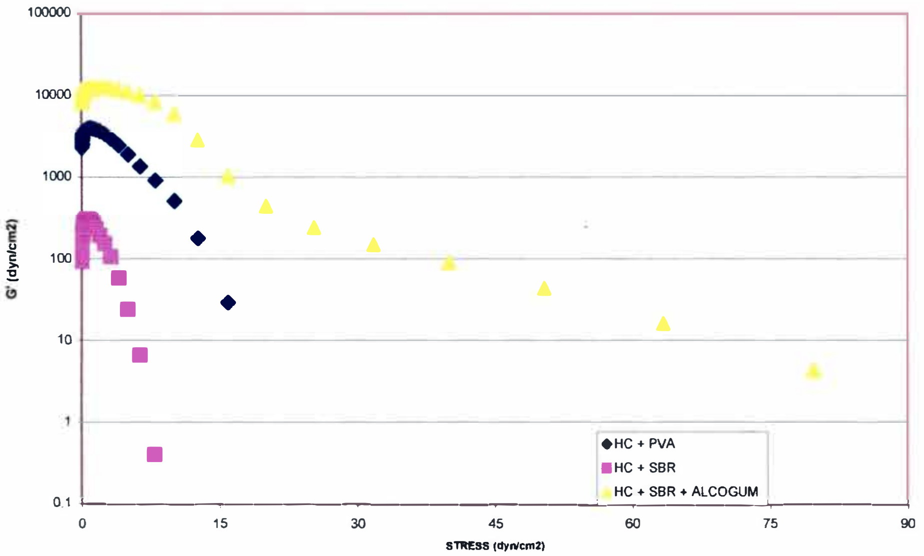

Fig.7. Rheological characterization (G') of carbonate systems without borate compound, **Control 1**. Freq=1.

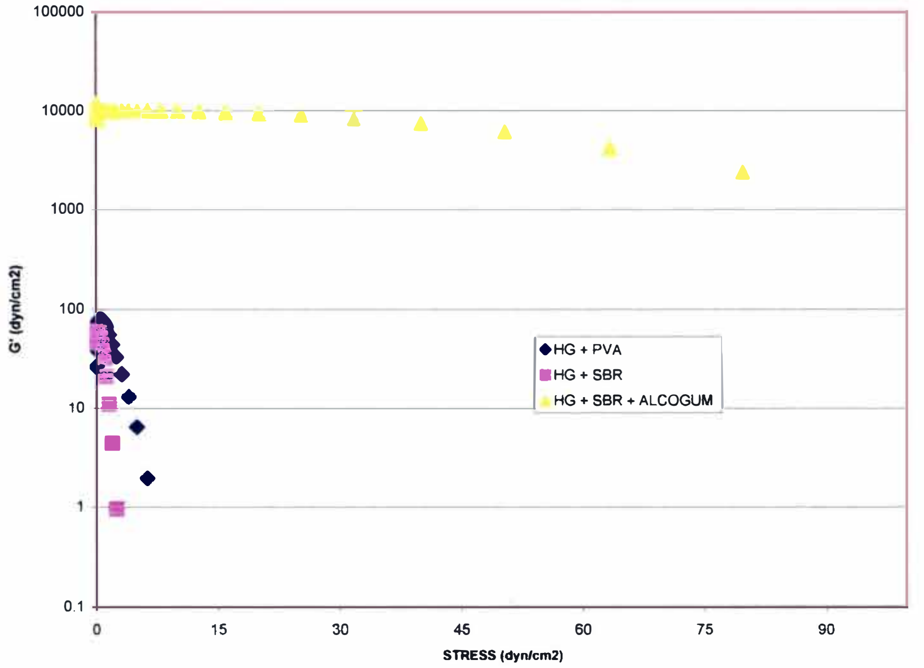

Fig.8. Rheological characterization (G') of clay systems without borate compound, **Control 2**. Freq=1.

Effects of borates on the pigments

The results showed that the carbonate and clay pigments strongly interact with all the borate products. The strength of these interactions and the amount of interactivity (where strength relates to the force required to break the structure, higher the force greater the strength. The amount refers to the strength at the initial low stresses) increased with the concentration of borate as is evident from the G' and G" values.

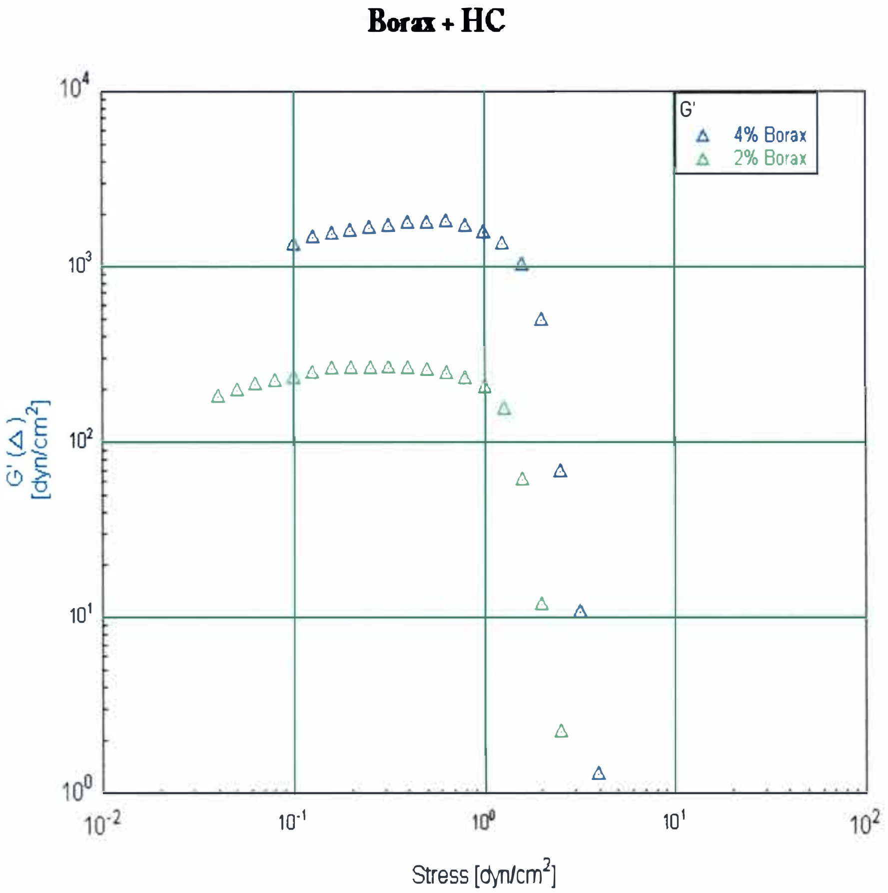

Fig.9. Viscoelastic response to dynamic stresses of Pigment dispersion containing borax and carbonate, Borax + HC, Freq=1. Borax at 2% and 4% of weight.

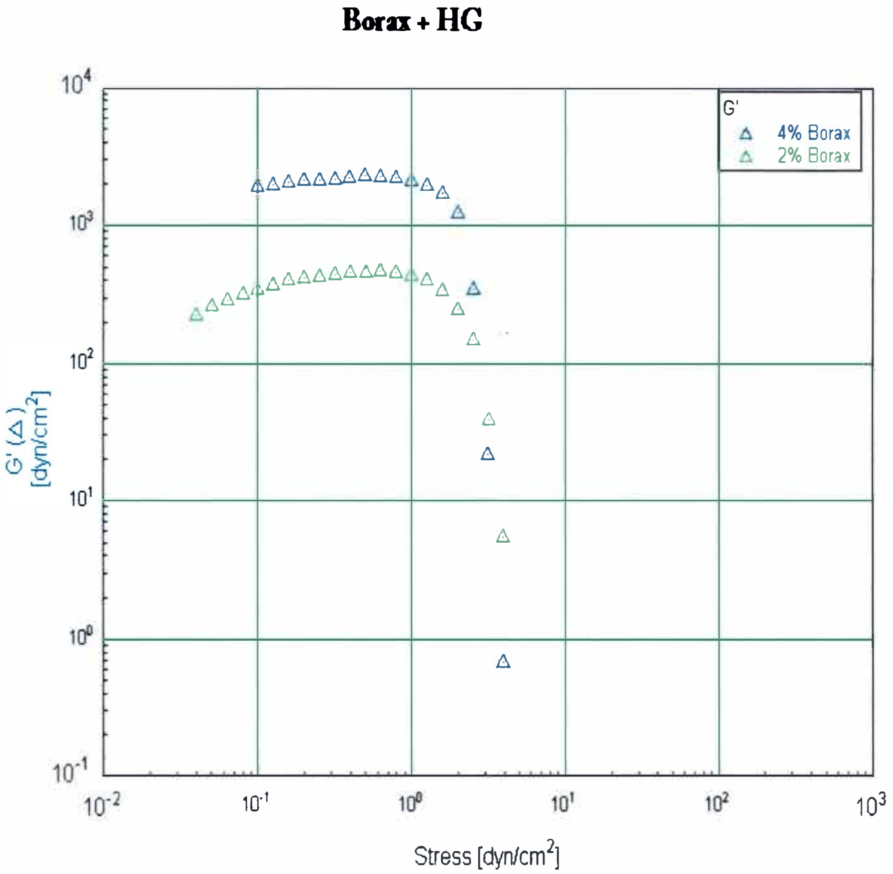

Fig.10. Viscoelastic response to dynamic stresses of Pigment dispersion containing Borax and clay, borax + HG, Freq=1, Borax at 2% and 4% of weight.

As seen in Figures 9 and 10, the amount and strength of interaction is greater for the carbonate than for the clay. Suggesting a higher interaction of borax with the carbonate than with the clay. The same is true for polybor (Fig.12.) but neobor interacts more with the clay than the carbonate (Fig.11.).

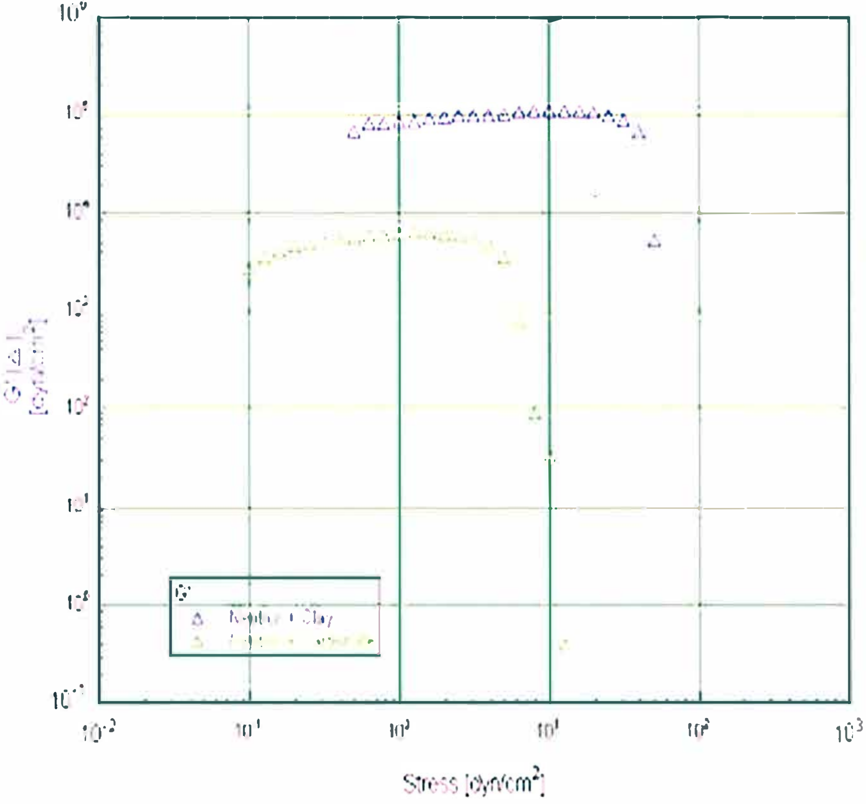

Fig.11. Viscoelastic response to dynamic stresses of Pigment dispersion containing Neobor and pigment, Neobor + Pigment (HC, HG), Freq=1.

For carbonate systems, the degree of interactions decreases in the order of Polybor, Neobor, and, Borax and for clay systems it decreases in the order of Neobor, Polybor, and Borax.

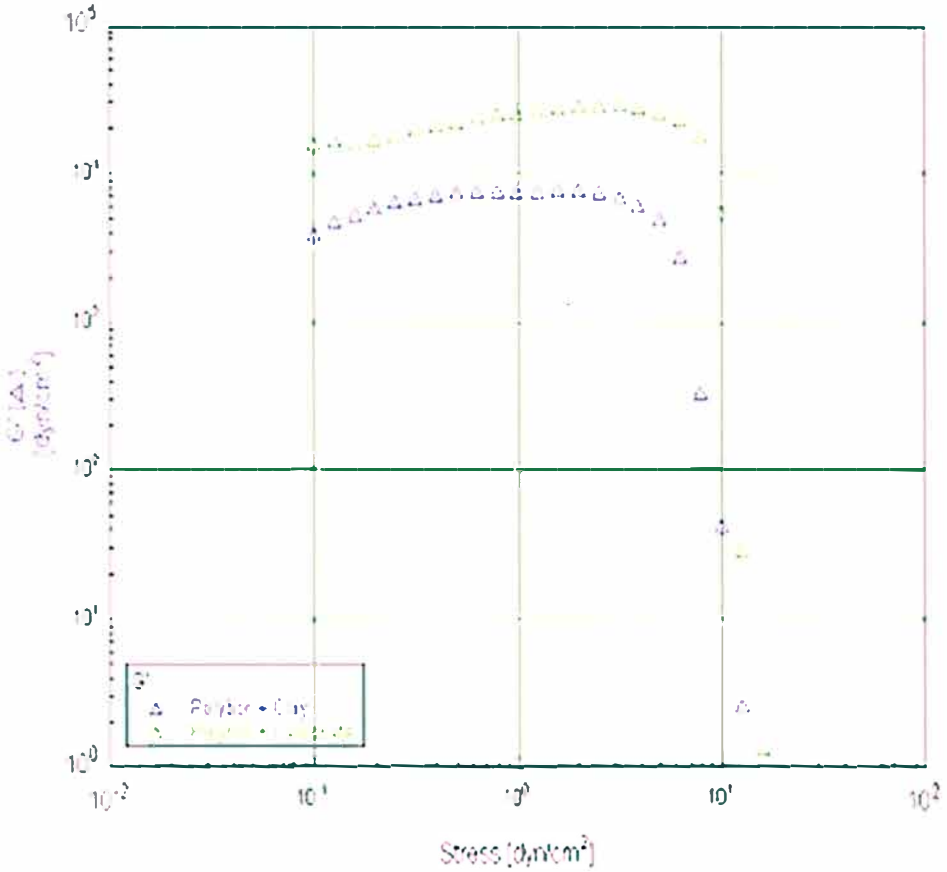

Fig.12. Viscoelastic response to dynamic stresses of Pigment dispersion containing Polybor and pigment, Polybor + Pigment (HC, HG), Freq=1.

The pH was in the required range. Though there was an increase in the pH with an increase in the amount of borate, the increase was not significant. The results from the Brookfield viscometer show that the viscosity increased with the concentration of borate (Fig 13.).

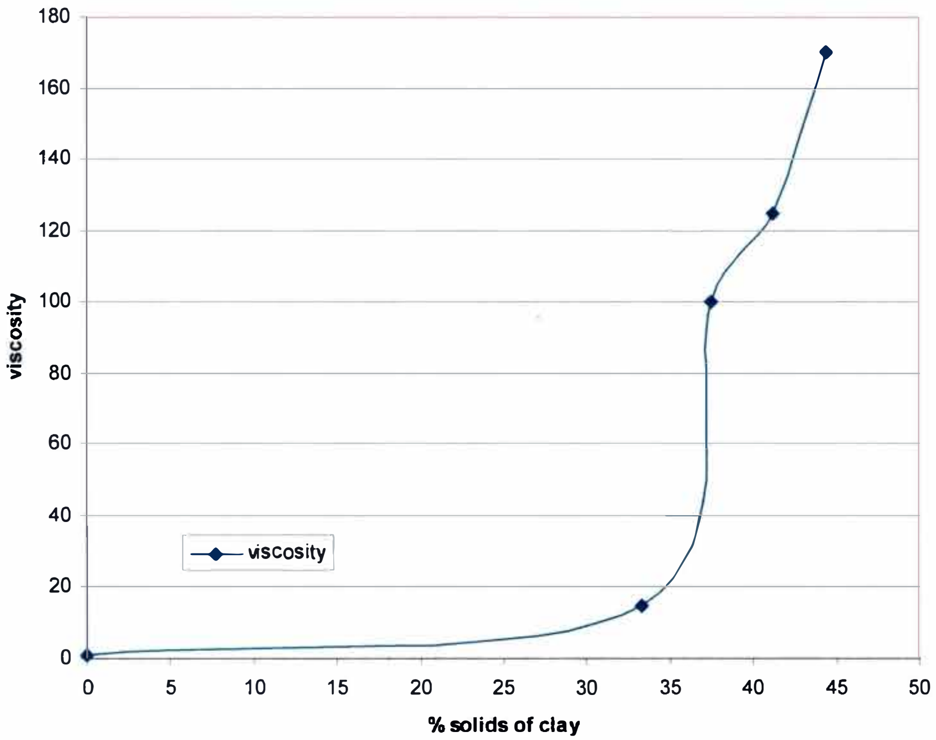

Fig.13. Change in viscosity with amount of Polybor and clay. Viscosity Vs % solids of clay (Polybor + HG), measurements are made at 100 rpm.

Effect of borates on binders and thickener

Here also the results showed the pigments and binders strongly interacted with all the borate products. The strength of these interactions and the amount of interactivity increased with the concentration of borate as is evident from the G' and G" values. This is explained further in detail in the following sections.

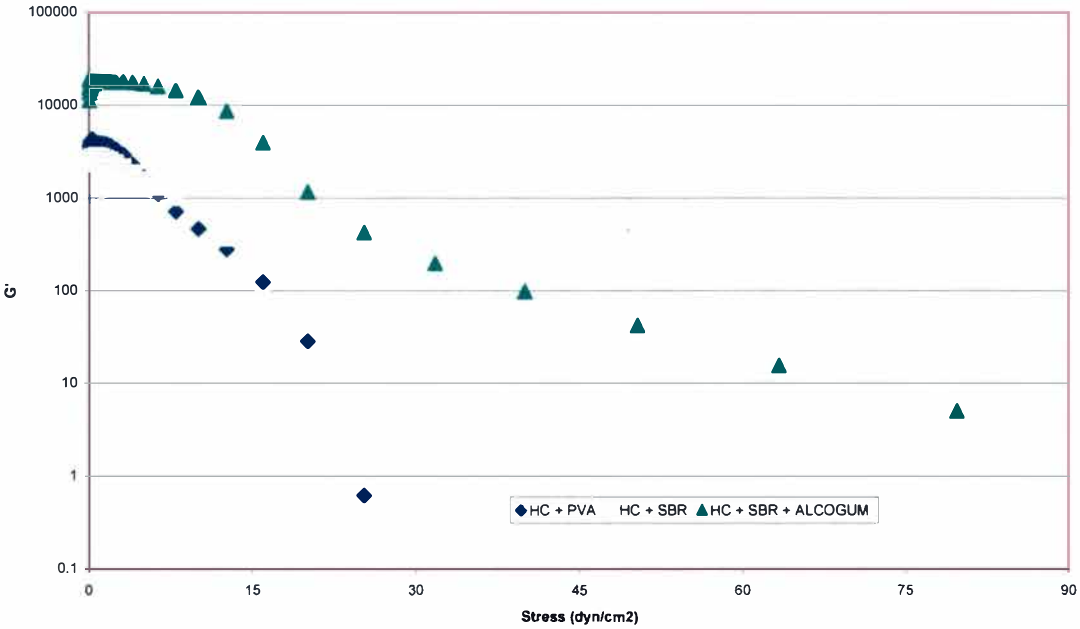

Fig.14. Influence of Borax on viscoelastic properties of carbonate systems, (G'), Freq=1.

Comparing Figures 14 and 15 with controls 1 and 2 (Figs. 7 and 8), there is an increase in G′ values for all carbonate and clay systems with the addition of borax. Elastic modulus, G′ values increase approximately 10 folds for all clay systems suggesting a strong borax interaction and all the curves retain their shape. There is an approximately 10 fold increase in elastic modulus, G′ values, for the carbonate-SBR system with borax addition but there is only a marginal increase in G′ values for carbonate systems with thickener as it strongly cross links with binders. This is also evident if the results from steady stress sweep tests below are examined.

The initial G' value for the carbonate systems is higher than the clay system. The carbonate-PVA system's yield stress is smaller than the clay-PVA system indicating a stonger structure. But, when the SBR systems are examined, the carbonate-SBR is stonger and also the G' value is higher. So with clay-PVA, the borax gives a stronger structure than the carbonate-PVA. With carbonate-SBR, the borax gives a stonger structure than the clay-PVA system.

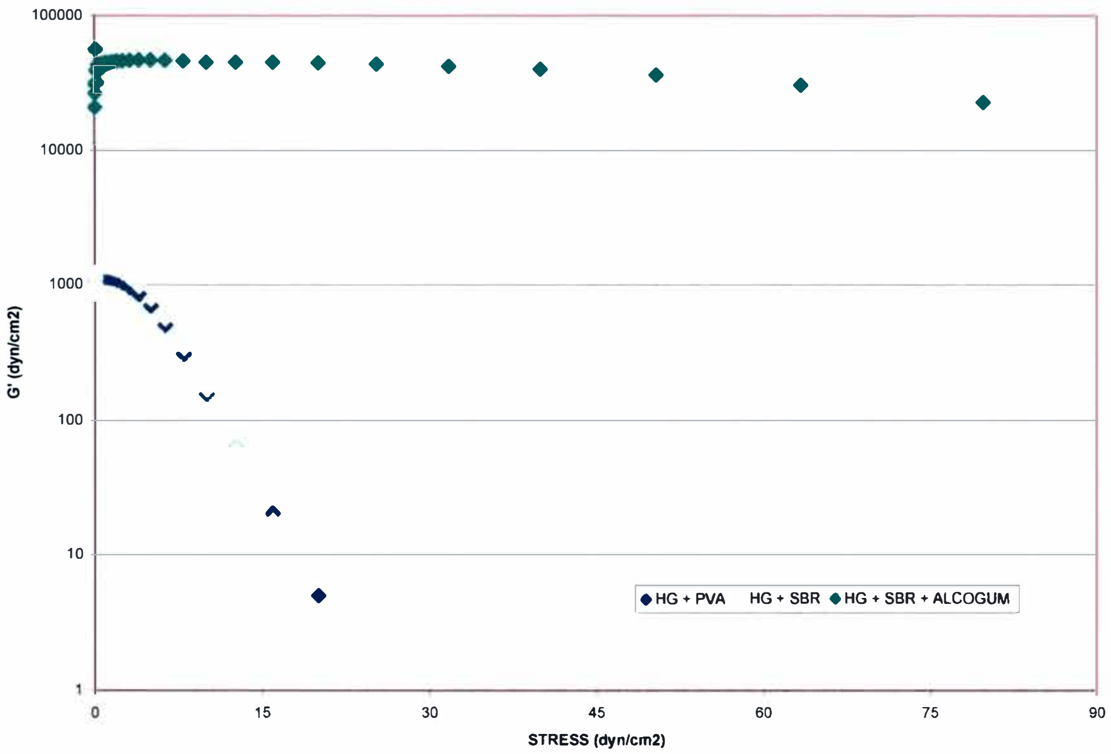

Fig.15. Influence of Borax on viscoelastic properties of clay systems, (G'), Freq=1.

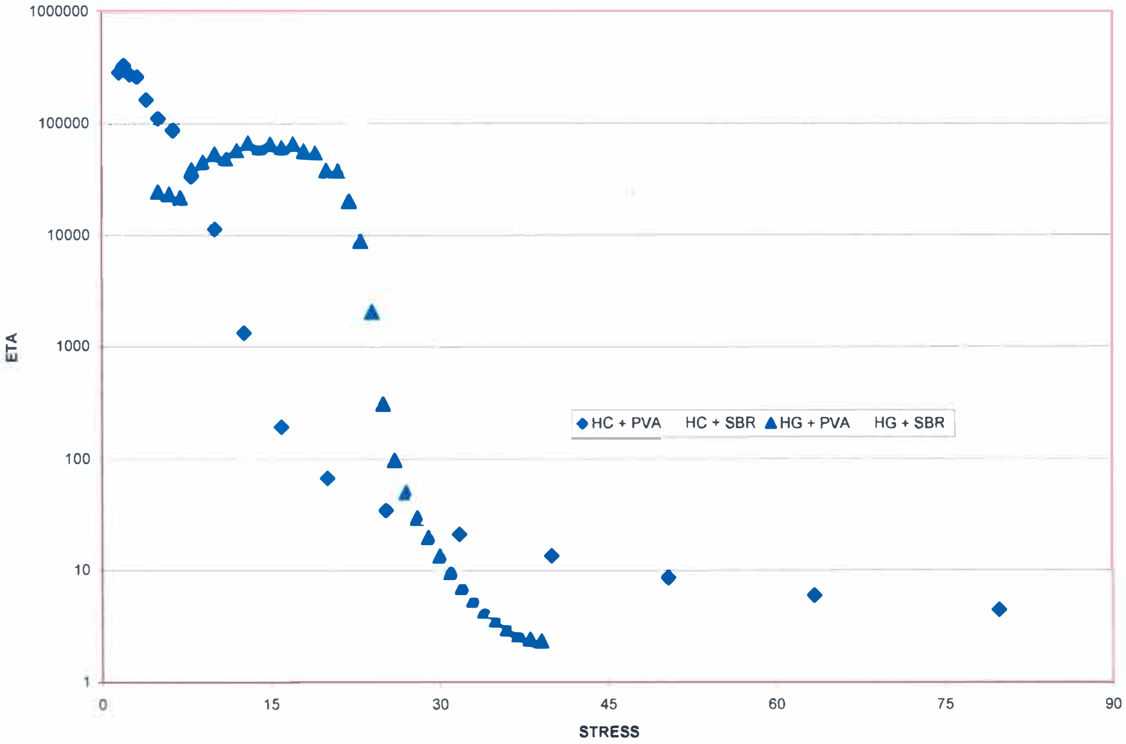

Fig.16. Apparent viscosity response to a steady stress for coatings with Borax, for both clay and carbonate systems.

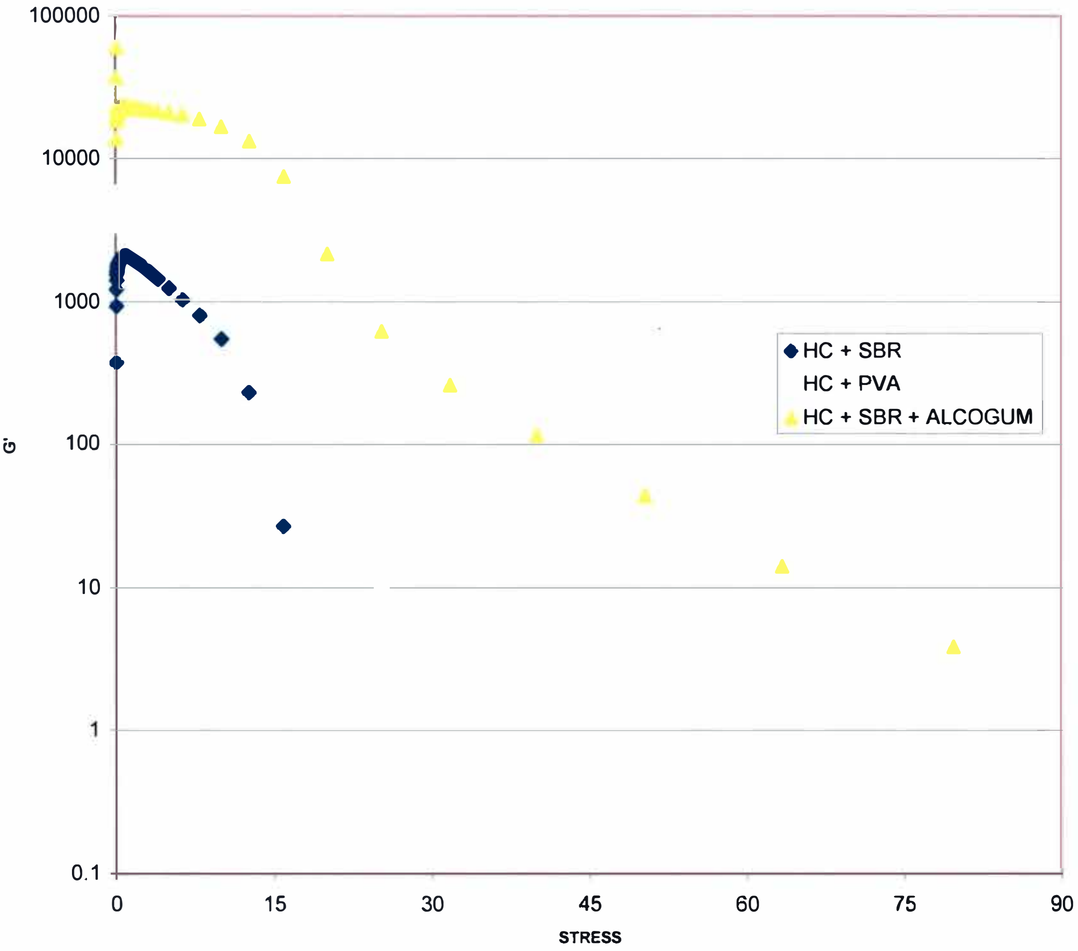

Fig.17. Influence of Neobor on viscoelastic properties of carbonate systems, (G'), Freq=1.

Comparing Figures 17 and 18 with controls 1 and 2 (Figs. 7 and 8), there is an increase in G′ values for all carbonate and clay systems were the addition of neobor. Elastic modulus, G′ values, increase approximately 10 folds for all carbonate systems suggesting a strong neobor interaction and all the curves retain their shape. There is a approximately 10 fold increase in elastic modulus, G′ values, for clay-SBR and clay-thickener systems with neobor addition but there is only a marginal increase in G′ values for clay-PVA system.

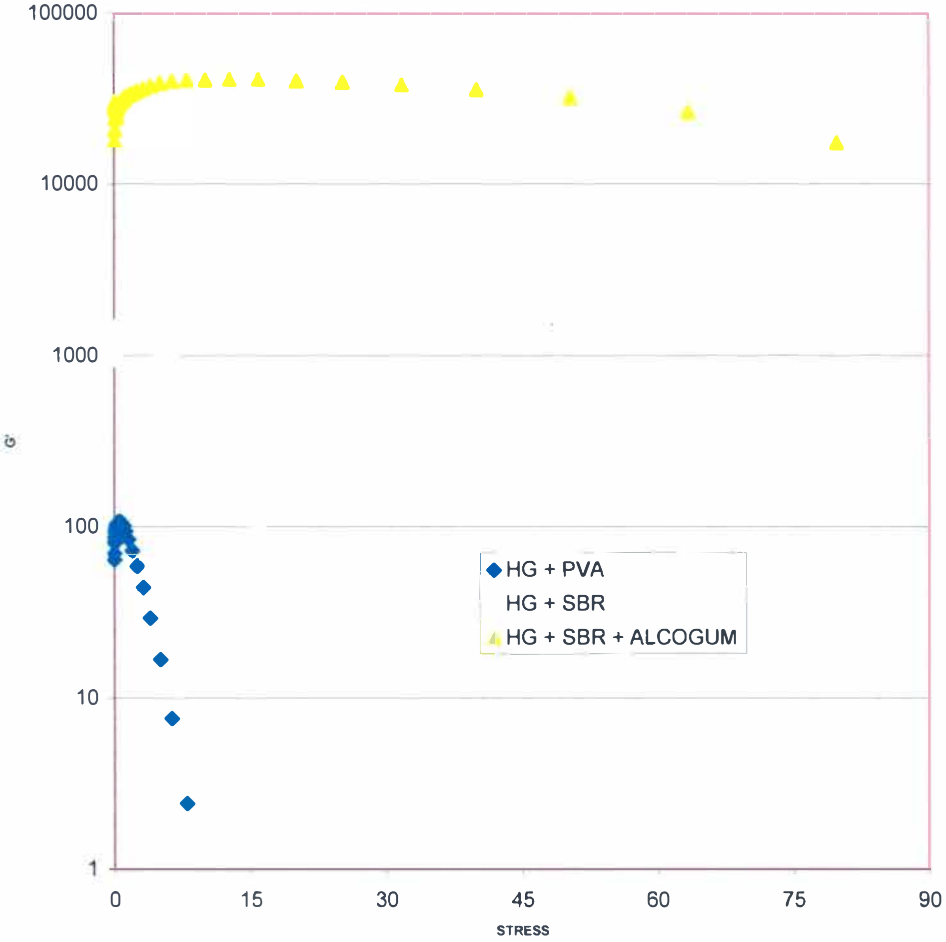

Fig.18. Influence of Neobor on viscoelastic properties of clay systems, (G'), Freq=1.

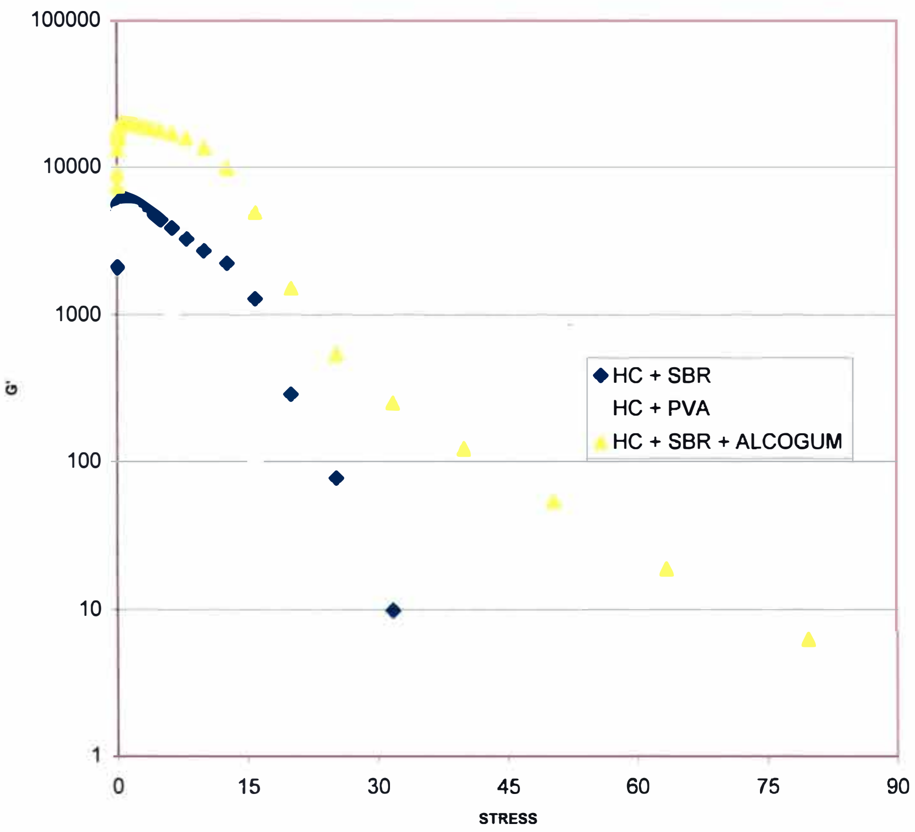

Fig.19. Influence of Polybor on viscoelastic properties of carbonate systems, (G'), Freq=1.

Comparing Figures 19 and 20 with controls 1 and 2 (Figs. 7 and 8), there is an increase in G′ values for all carbonate and clay systems on addition of polybor. Elastic modulus, G′ values increase approximately 10 folds for all carbonate systems suggesting a strong polybor interaction and all the curves retain their shape. There is a approximately 10 fold increase in elastic modulus, G′ values for clay-SBR and clay-PVA system with polybor addition but there is only a marginal increase in G′ values for clay systems with thickener as it strongly cross links with binders.

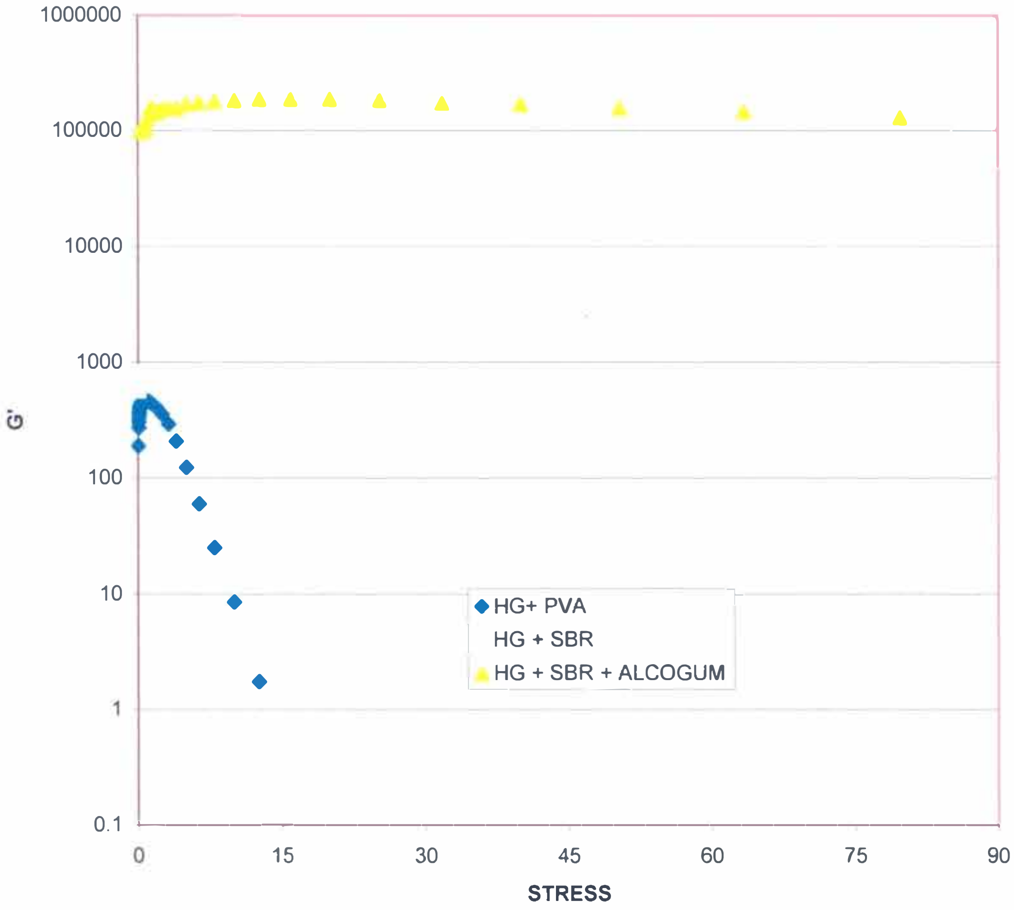

Fig.20. Influence of Polybor on viscoelastic properties of clay systems, (G'), Freq=1.

There is an increase in the pH (Fig.21.) and viscosity of the system with the addition of the thickener. The pH remained in the range of 8.5-10.5 and the increase in the viscosities suggests that it should not create problems of runnability.

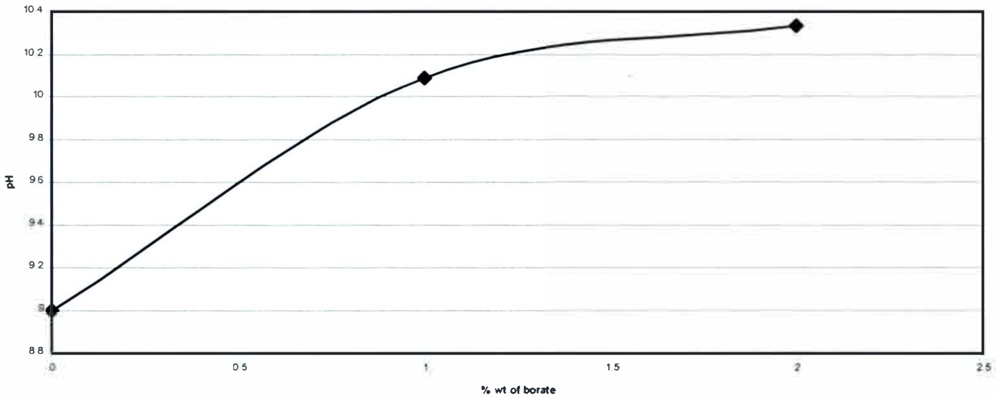

Fig.21. Change in viscosity with amount of Neobor in a Neobor-thickener system.

The advantages of the interactions are, the strength of the system in increased due to these interactions, but also the structure breaks down with the application of stress, suggesting a shear thinning behavior. There is sudden increase in the viscosity of the system with the addition of borates, suggesting borates can be used as bulking agents. There are interactions between borates and pigments and borates and binders, which means the amount of binders in the coating systems can be reduced, with the use of borates.

High shear characteristics

All the coatings tested for high shear characteristics show shear thinning behavior. The increase in amount of borate resulted in the shift of the hysteresis loop towards the right, suggesting an increase in the strength of the system (more torque required to obtain a desired rpm). Also an increase in the amount of borate used, increased the area of the loop, suggesting an increase in the relaxation or recovery time (Figs.22, 23, and, 24).

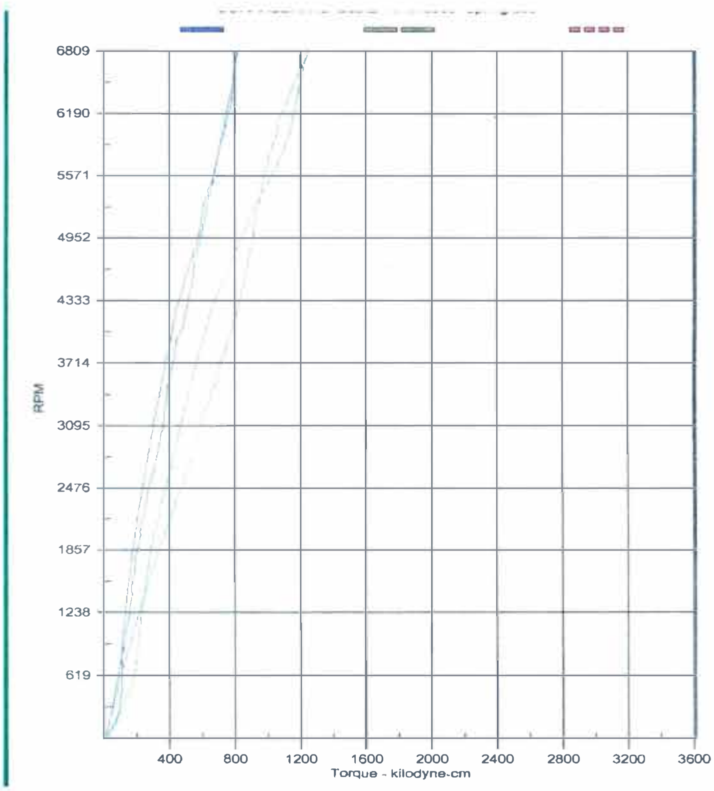

Fig.22. High Shear data from Hercules viscometer for Borax and clay, with the increasing amount of borax. 0, 1, and 2% borax, loops from left to right.

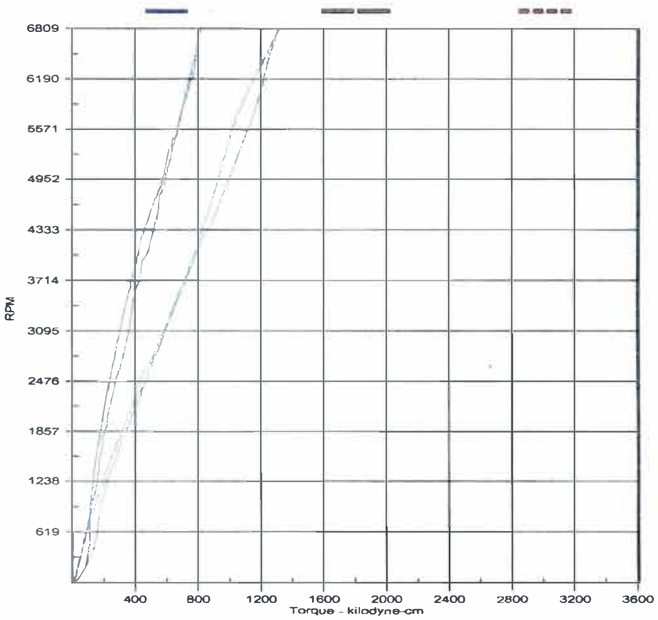

Fig.23. High Shear data from Hercules viscometer for Neobor and clay, with the increasing amount of Neobor. 0, 1, and 2% neobor, loops from left to right.

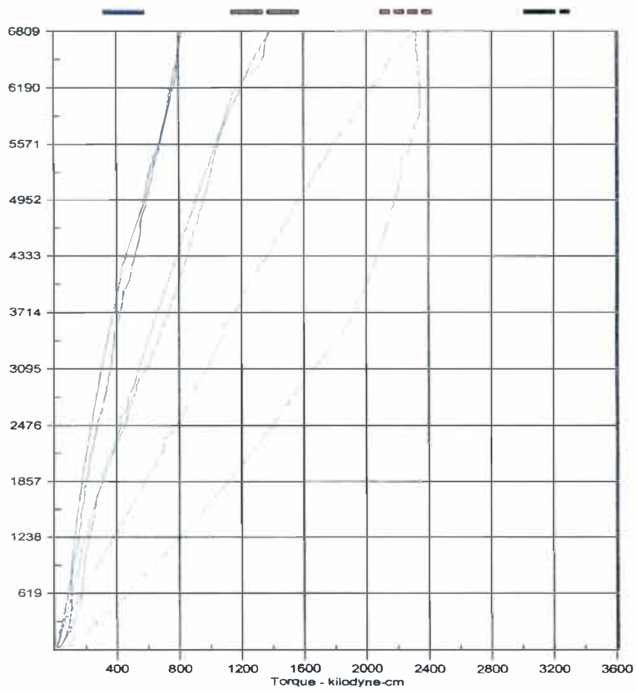

Fig.24. High Shear data from Hercules viscometer for Polybor and clay, with the increasing amount of Polybor. 0, 1, and 2% polybor, loops from left to right.

CHAPTER VI

CONCLUSIONS

1) All borates strongly interacted with pigments, binders, and thickener.

2) Interactions between borates and coating constituents increased with the concentration of borates.

3) The low shear studies indicated that addition levels of borates of less than 1 % on weight of pigment could be used without affecting the low shear rheology of the coating.

4) The high shear studies indicated that addition levels of borates higher than 1% on weight of pigment can be used without affecting the high shear rheology of the coating.

5) The differences between the low shear and high shear rheological data indicates, although interactive, the strength of these interactions is not sufficient to withstand the shear forces that would be experienced during application and metering of the coating. Therefore, this would eliminate concerns with using them in a paper coating system. However, if more than 1% on weight of pigment is required to obtain the IR drying benefits, care must be taken to keep the coating well mixed prior to application and in the coating pan. The recirculation rate of the coating should be sufficient to prevent viscosity increase due to the low shear interactions of the borates with the coating pigments.

6) The interaction between the borates and coating pigments may improve coating bulk, and coverage, and the leveling properties of the coating.

CHAPTER VII

RECOMMENDATIONS

It is recommended that a further study be initiated. This study should determine the increase in IR drying efficiency due to the borates. The study should be confined to basic coating formulations, as used in this study. A simple way of determining the increase in drying is to measure the moisture content in the papers with and without borates. A laboratory coater equipped with an IR dryer might be used. The experiments might be done altering the IR intensity and the time of exposure. There should be some effort put into finding a way to increase the amount of borate used or a new borate material might be used which has a solubility at a lower temperature, i.e., at room temperatures. The study should also concentrate on other benefits of borates, such as whether the borates are able to improve the coating bulk. Measuring the opacity can determine the bulking properties of the borates. So, different paper properties should be measured and checked for improvement in any of them.

The basic experimental plan should include the making of coating formulations using basic coating components like pigment, binder, rheology modifier (to control the viscosity), alkali (to control the pH), and water as used in this study. Most commonly used substances like clay, carbonates, and styrene butadiene should be used. The coatings should be made at certain solids percentage, viscosity, and pH. The coatings should contain different levels of different borates starting from no borate.

The coatings should be run on a laboratory coater equipped with an IR dryer with facility to adjust the IR intensities and the time of exposure. The same base sheet should be used to coat with the coatings. After coating the paper, different properties should be measured to determine the effect of borates.

In addition to the above-mentioned tests, the paper can be printed and different printing properties can be measured to determine if there is any effect of borates on the printing properties like wet pick and rub resistance.

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APPENDIX

Steady stress data for all borate systems.

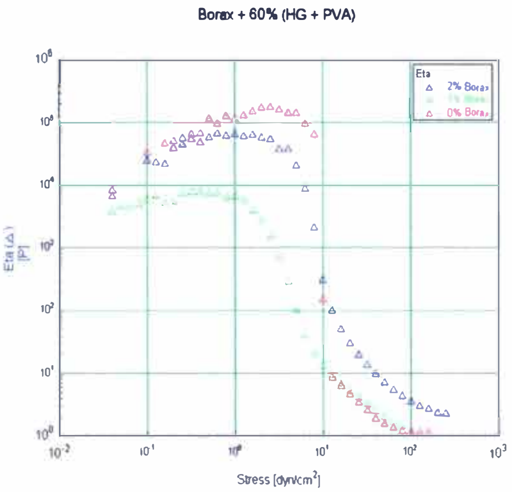

Fig. A-1. Steady stress sweep data of borax, clay and PVA system.

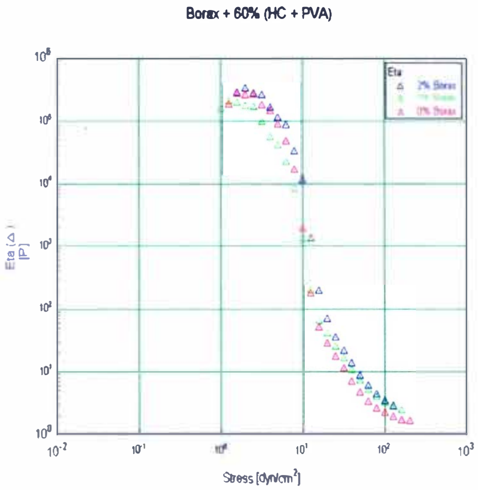

Fig. A-2. Steady stress sweep data of borax, carbonate and PVA system.

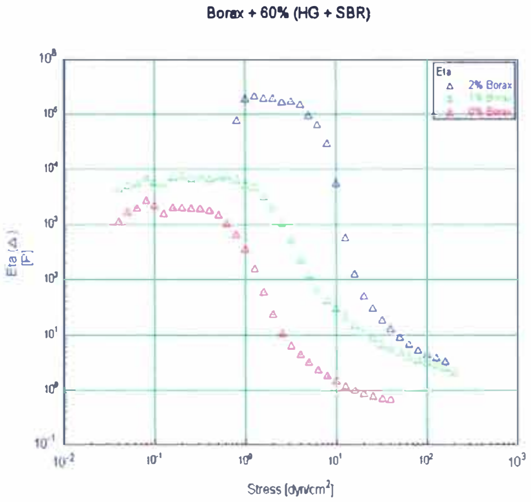

Fig. A-3. Steady stress sweep data of borax, clay and SBR system.

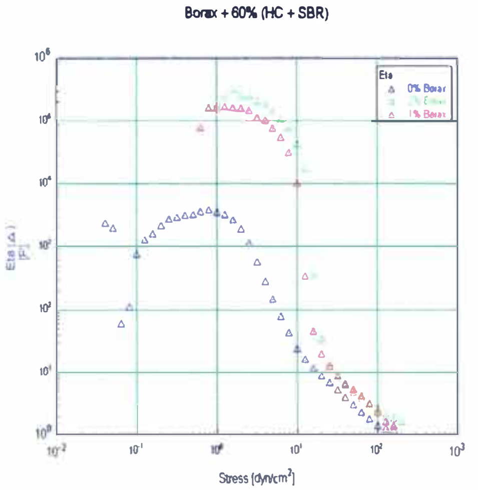

Fig. A-4. Steady stress sweep data of borax, carbonate and SBR system.

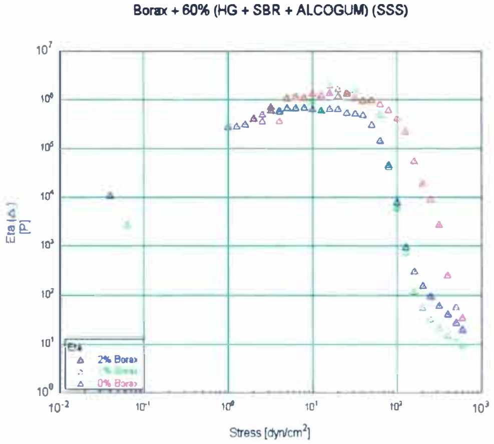

Fig. A-5. Steady stress sweep data of borax, clay, SBR and Alcogum system.

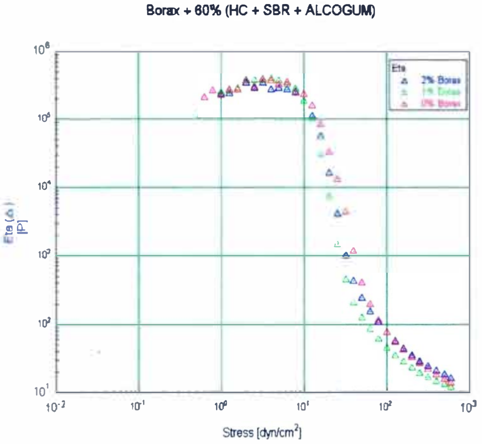

Fig. A-6. Steady stress sweep data of borax, carbonate, SBR and Alcogum system.

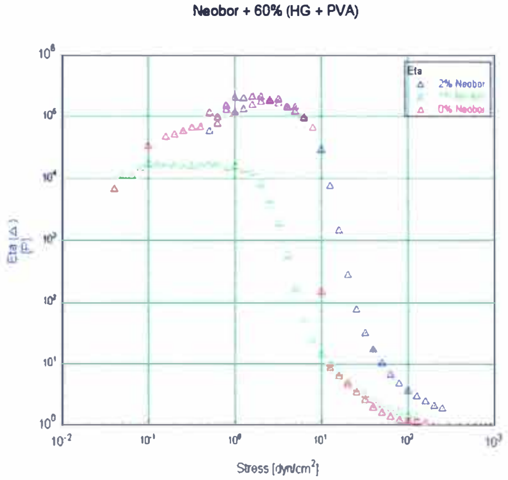

Fig. A-7. Steady stress sweep data of neobor, clay and PVA system.

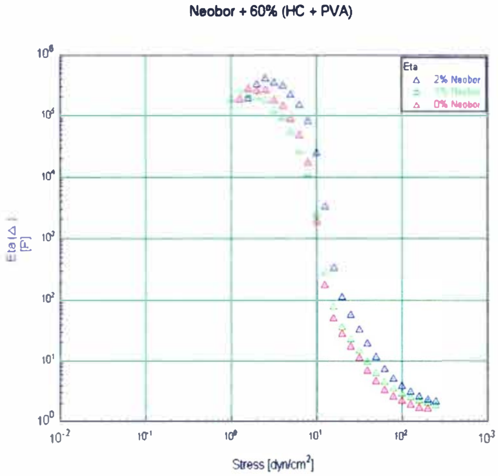

Fig. A-8. Steady stress sweep data of neobor, carbonate and PVA system.

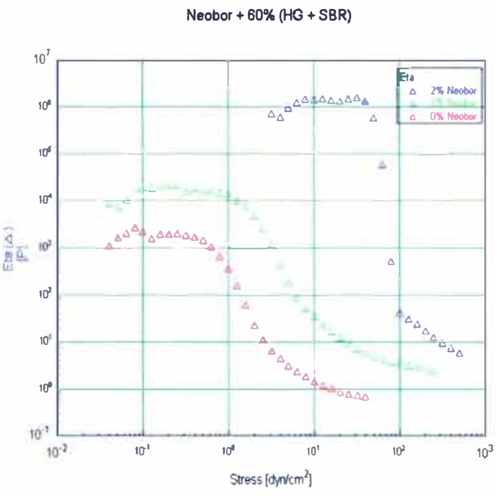

Fig. A-9. Steady stress sweep data of neobor, clay and SBR system.

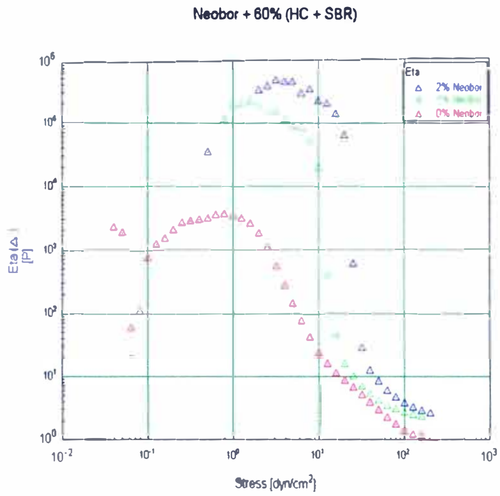

Fig. A-10. Steady stress sweep data of neobor, carbonate and SBR system.

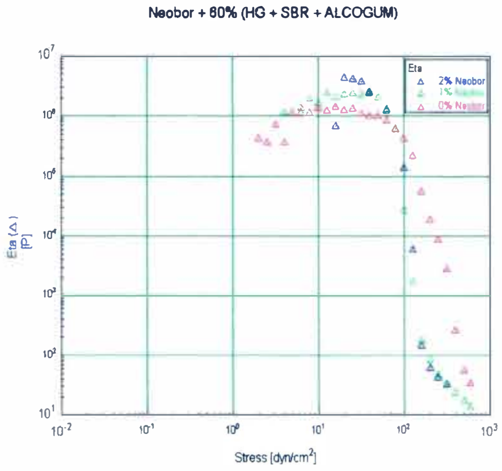

Fig. A-11. Steady stress sweep data of neobor, clay, SBR, and alcogum system.

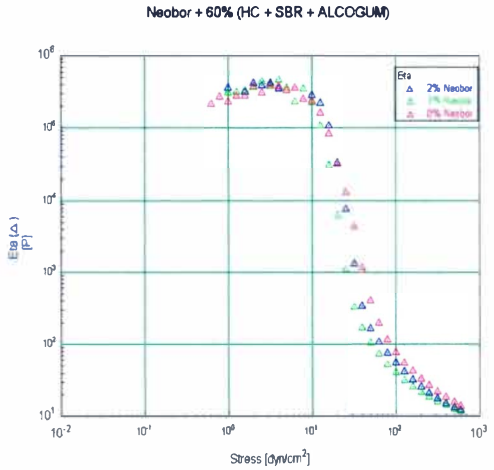

Fig. A-12. Steady stress sweep data of neobor, carbonate, SBR, and alcogum system.

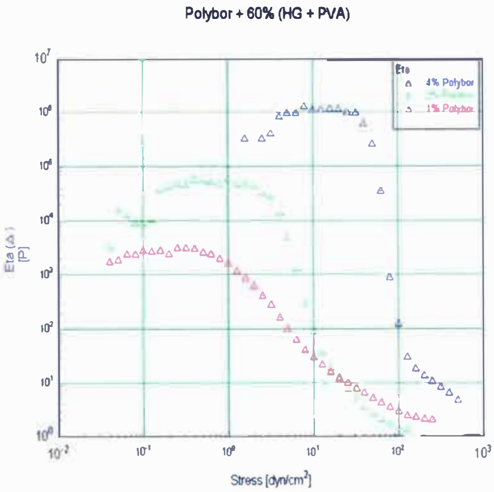

Fig. A-13. Steady stress sweep data of polybor, clay and PVA system.

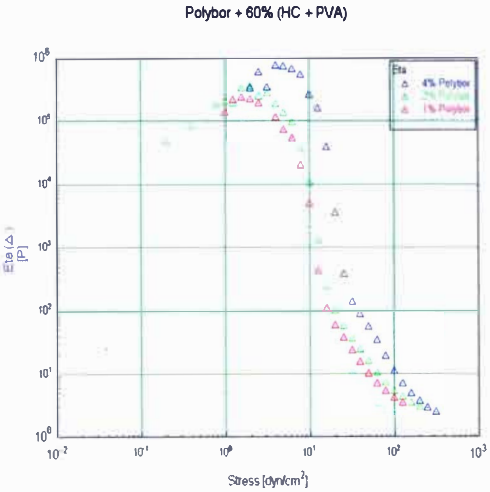

Fig. A-14. Steady stress sweep data of polybor, carbonate and PVA system.

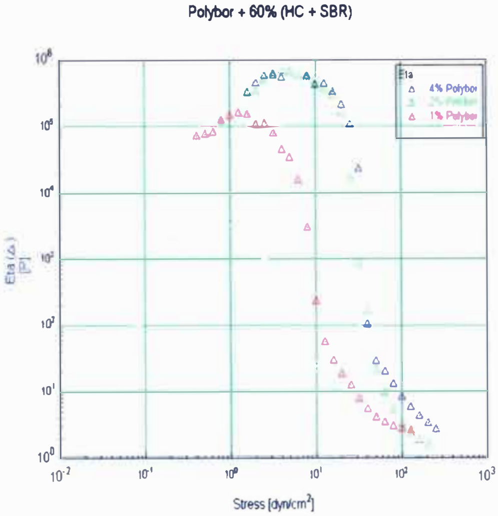

Fig. A-15. Steady stress sweep data of polybor, clay and SBR system.

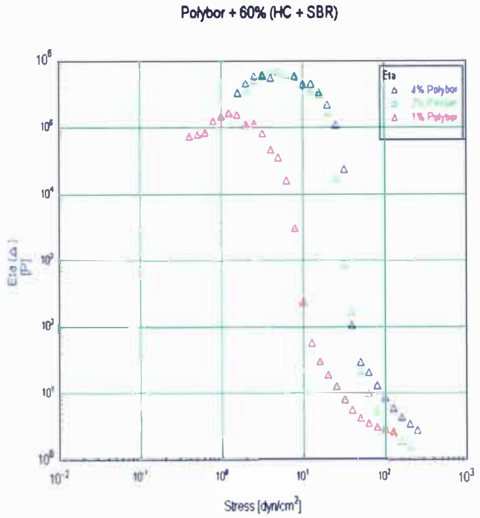

Fig. A-16. Steady stress sweep data of polybor, carbonate and SBR system.

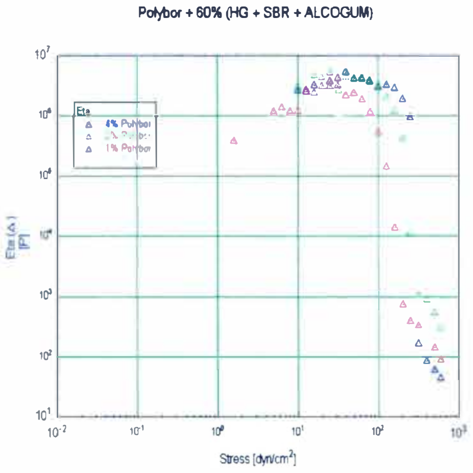

Fig. A-17. Steady stress sweep data of polybor, clay, SBR, and alcogum system.

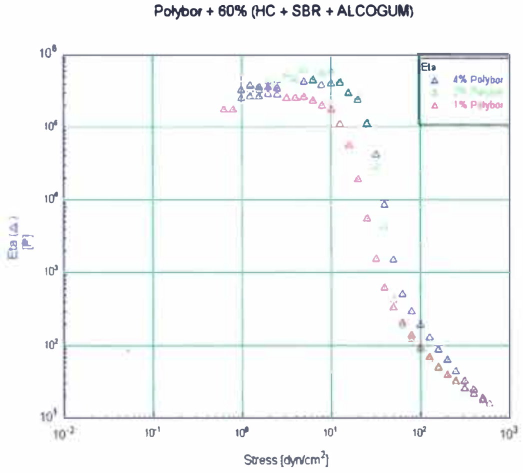

Fig. A-18. Steady stress sweep data of polybor, carbonate, SBR, and alcogum system.

Frequency stress sweep data for all borate systems

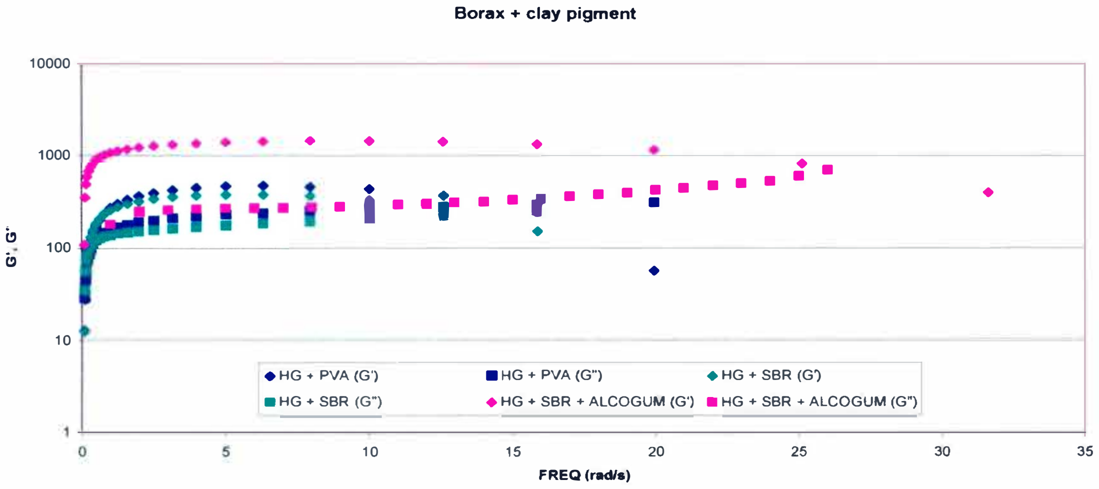

Fig. A-19. Frequency stress sweep data of borax-clay systems.
Freq. range – 1-100.

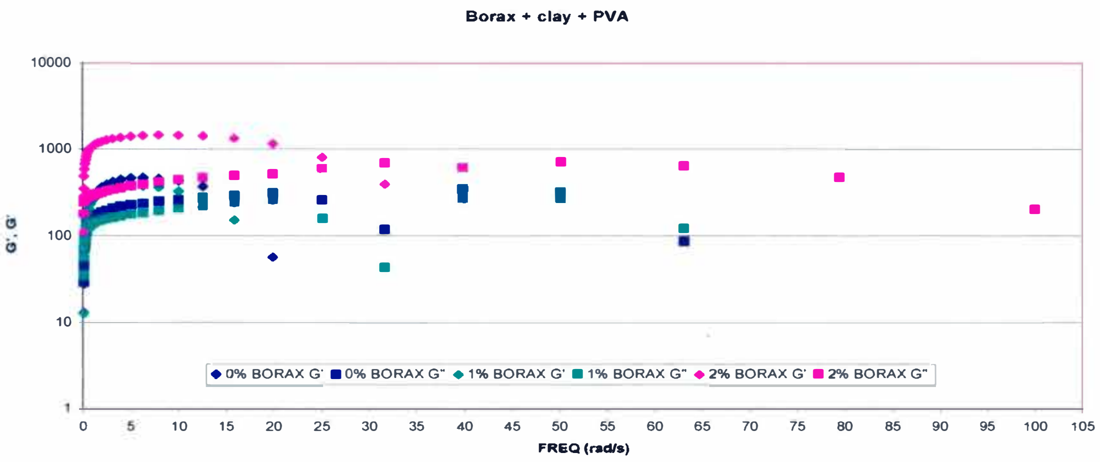

Fig. A-20. Frequency stress sweep data of borax-clay-PVA system, with varying borax concentrations. Freq. range – 1-100.

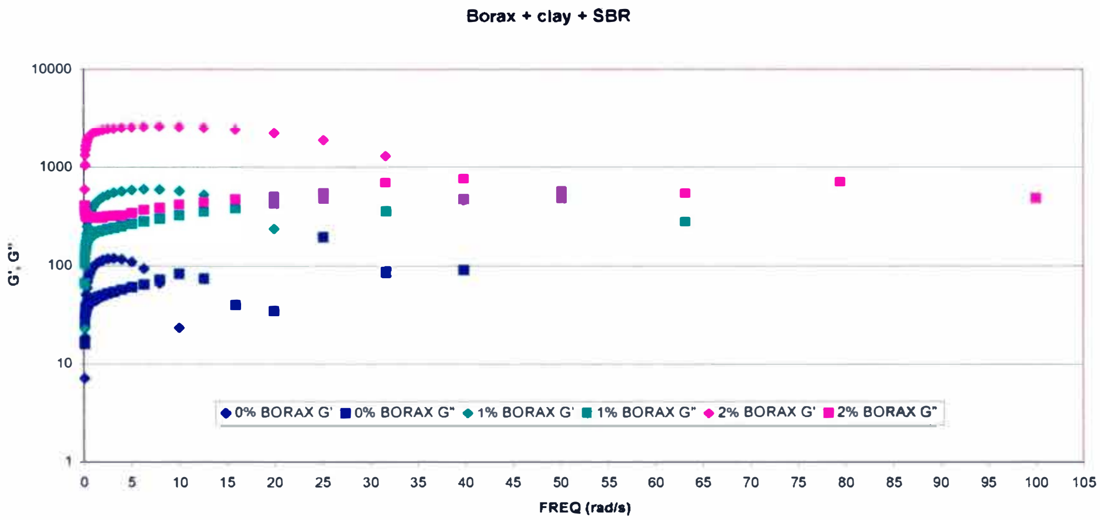

Fig. A-21. Frequency stress sweep data of borax-clay-SBR system, with varying borax concentrations. Freq. range – 1-100.

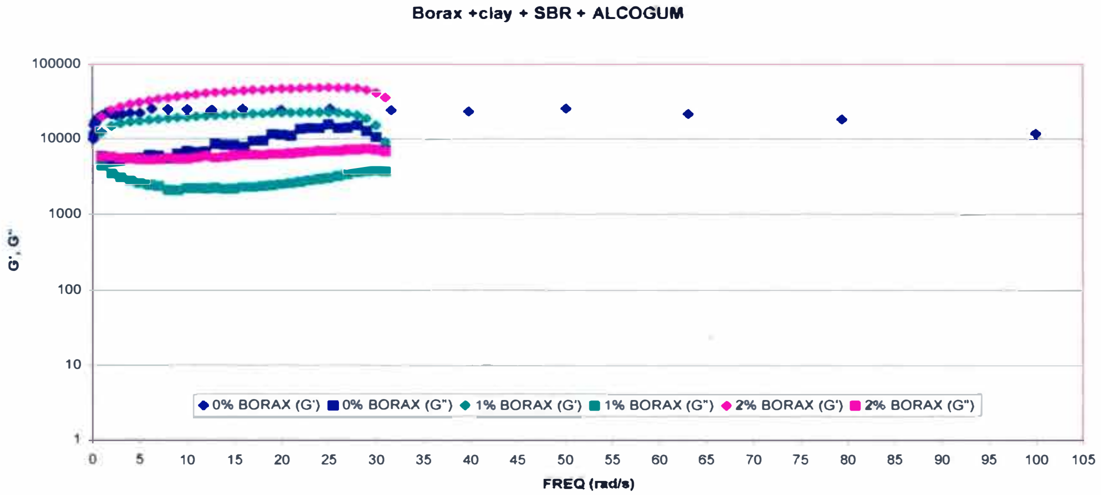

Fig. A-22. Frequency stress sweep data of borax-clay-SBR-alcogum system, with varying borax concentrations. Freq. range – 1-100.

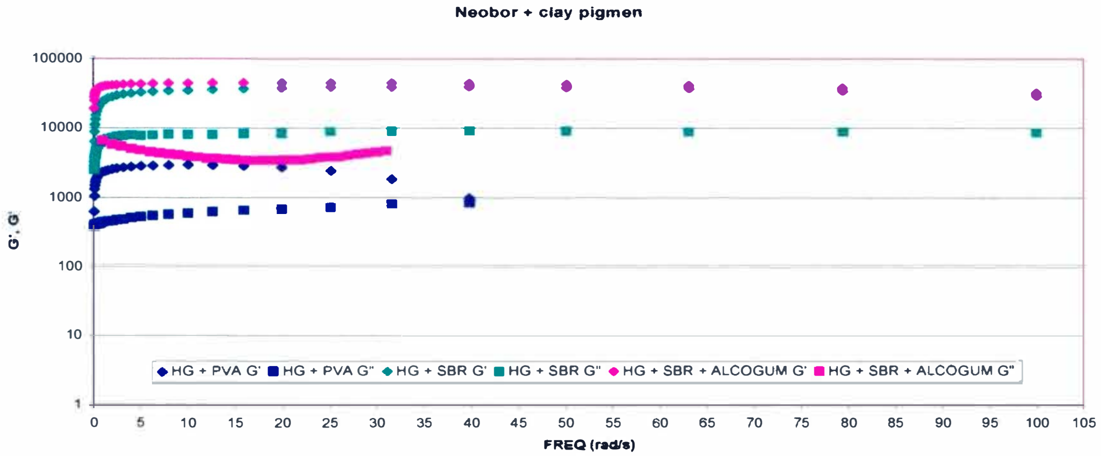

Fig. A-23. Frequency stress sweep data of neobor-clay systems.
Freq. range – 1-100.

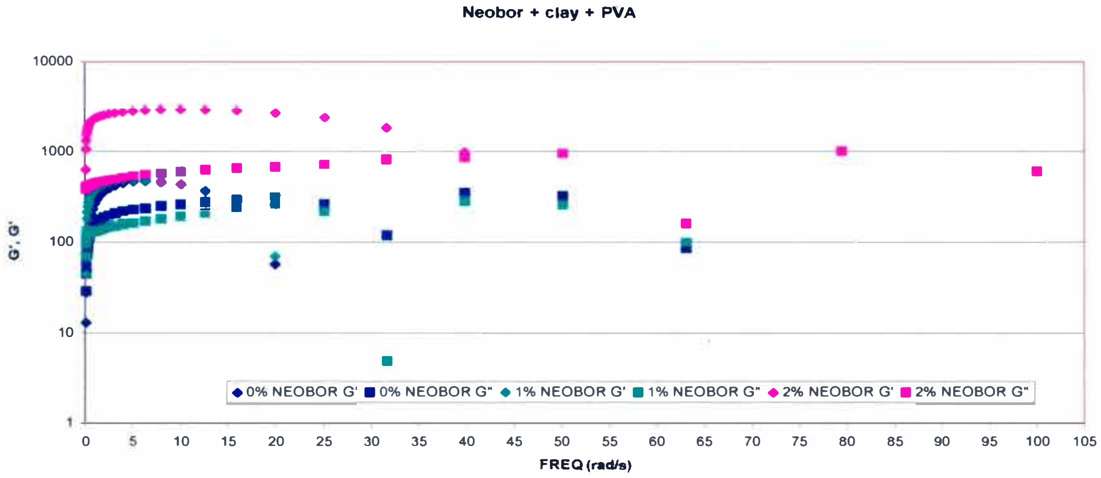

Fig. A-24. Frequency stress sweep data of neobor-clay-PVA system, with varying neobor concentrations. Freq. range – 1-100.

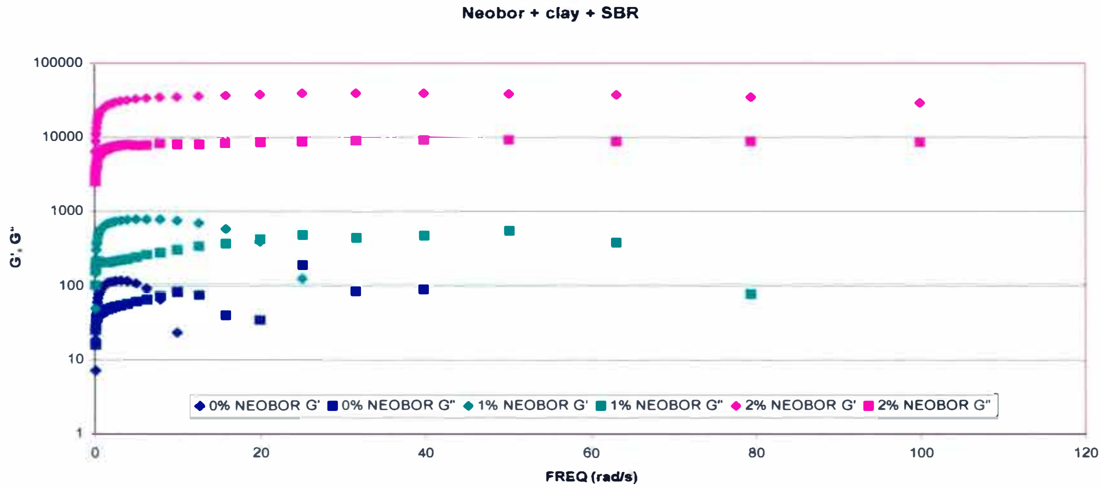

Fig. A-25. Frequency stress sweep data of neobor-clay-SBR system, with varying neobor concentrations. Freq. range – 1-100

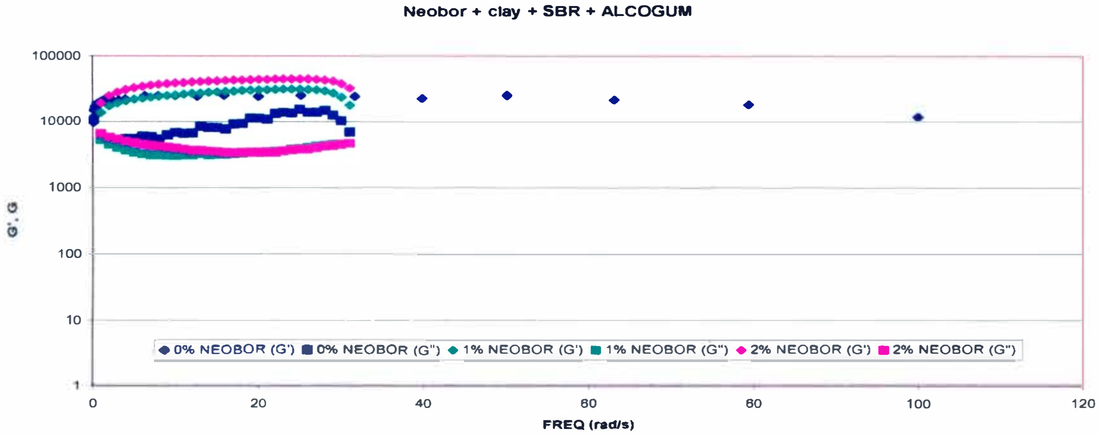

Fig. A-26. Frequency stress sweep data of neobor-clay-SBR-alcogum system, with varying neobor concentrations. Freq. range – 1-100.

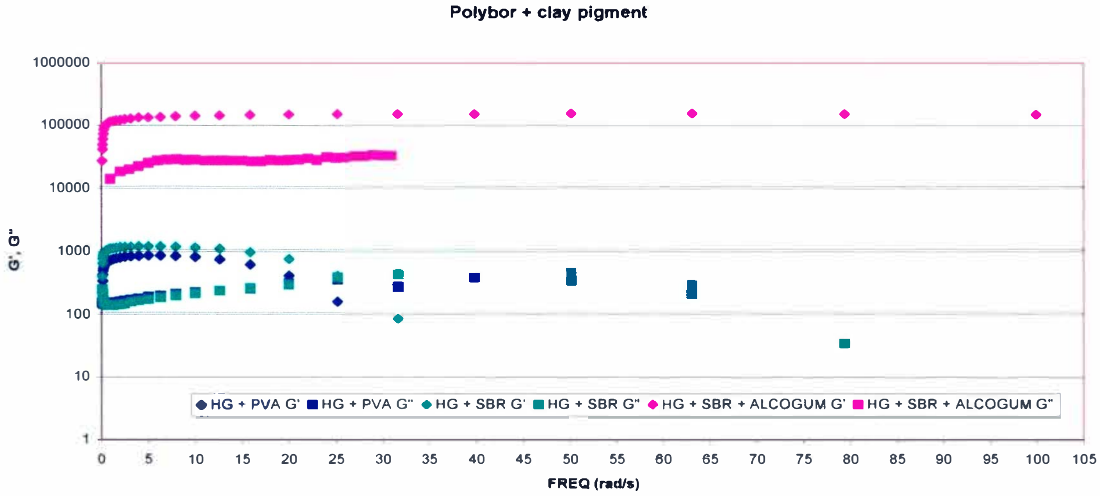

Fig. A-27. Frequency stress sweep data of polybor-clay systems.
Freq. range – 1-100.

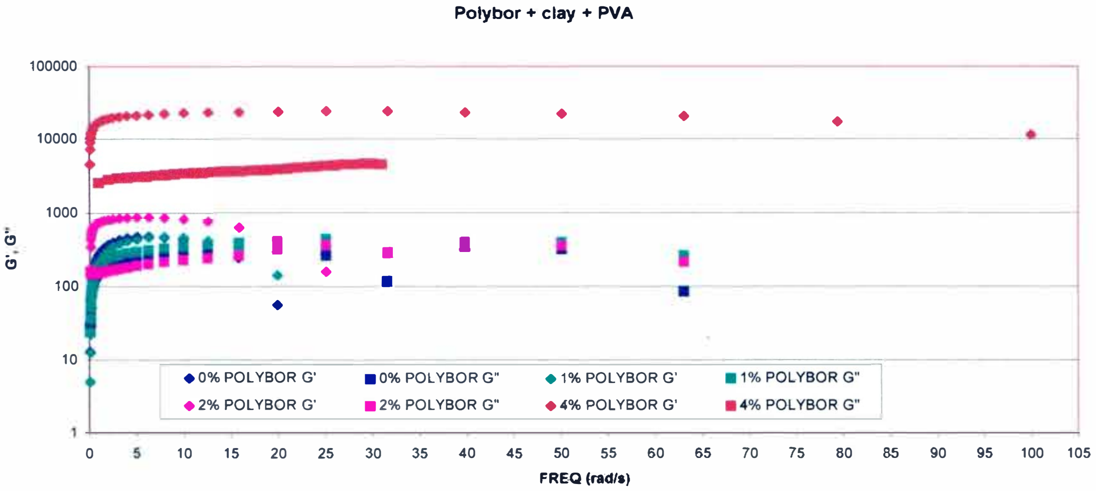

Fig. A-28. Frequency stress sweep data of polybor-clay-PVA system, with varying polybor concentrations. Freq. range – 1-100.

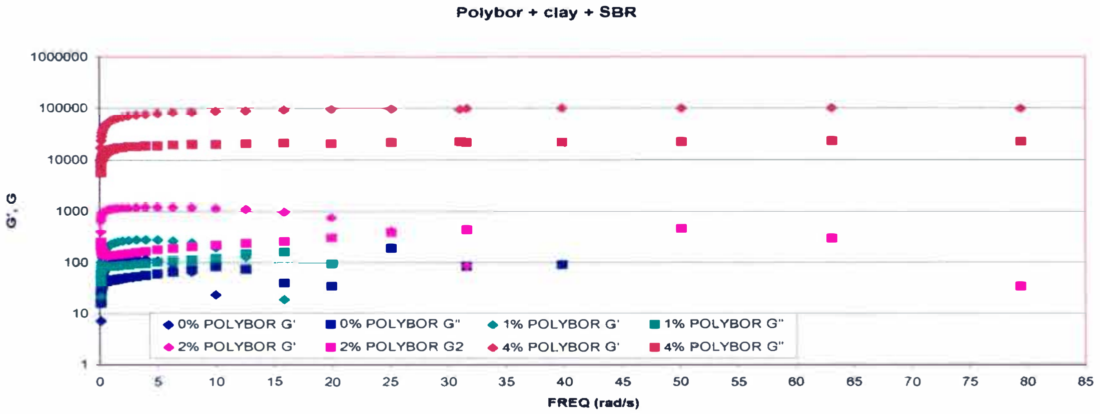

Fig. A-29. Frequency stress sweep data of polybor-clay-SBR system, with varying polybor concentrations. Freq. range – 1-100.

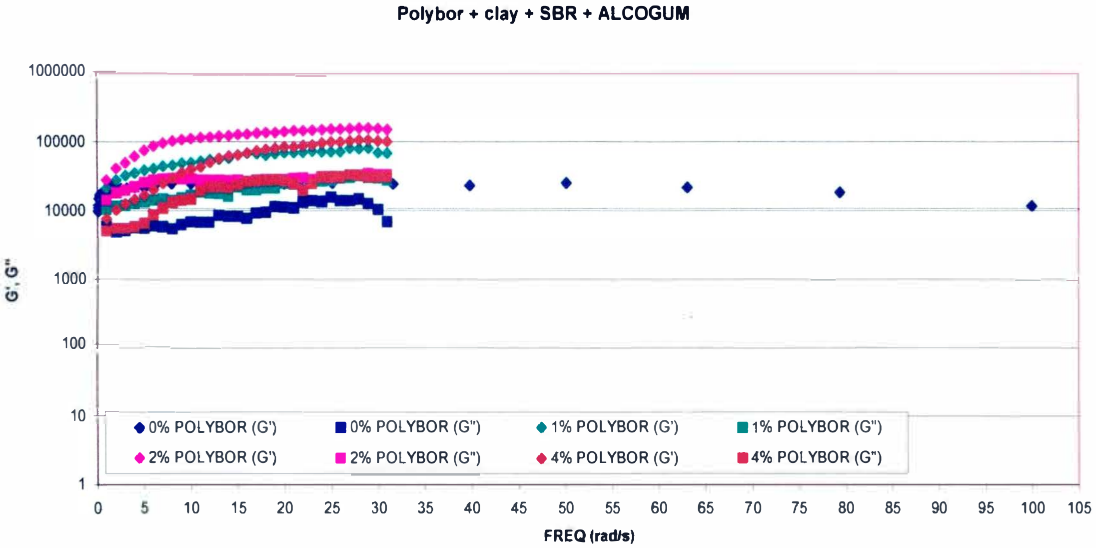

Fig. A-30. Frequency stress sweep data of polybor-clay-SBR-alcogum system, with varying polybor concentrations. Freq. range – 1-100.