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MD Ribbing Instability of Air Knife Coating Application

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A look at ribbing on the sheet caused by the film split of the coating application

By
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Abstract:

The coating application process is an area of great concern for most mills that produce a coated media. During the roll application of the coating onto the sheet, the fluid that is passed to the sheet from the roll, goes through a process known as film splitting. Film splitting is the mechanism for the transfer of the fluid from the application roll to the sheet. Instead of smoothly transferring onto the sheet, the film splits away from the roll and then onto the substrate. Without even transfer and leveling of the coating fluid, the splitting results in stripes or ribs on the paper in the machine direction. The result on the sheet is known as ribbing.

Fort James board mill of Kalamazoo, MI is currently experiencing this phenomenon with their coated board. Dr. Kim W. Robinson, Director of Technology at Fort James, Kalamazoo, has studied the ribbing effect, and it has been noticed that the ribbing follows a wave pattern in the machine direction transversely along the rolls. Ribbing is caused from the film split that is occurring between the roll and the sheet. The film split is a function of the low shear viscosity (LSV) and high shear viscosity (HSV) of the coating fluid.

The HSV of the fluid is related to the transfer of the coating while the LSV is related to the leveling effect of the coating. Good transfer and leveling of the coating yields good coating coverage on the sheet. A measure of good coating coverage can be determined by calculating the rheology index. The rheology index is the ratio of the HSV/LSV. Good coating surface appearance has been found at a rheology index of greater than 0.25 (3).

The viscosifier in the air knife coating formulation from FJ was replaced with carboxymethyl cellulose (CMC) and hydroxyethyl cellulose (HEC). Each thickener was used at low and medium molecular weights. The low shear viscosity was then calculated using the dynamic stress simulator. Next, the high shear viscosity was calculated using the Hercules viscometer.

The results showed that none of the air knife coating formulations had a rheology index of greater than 0.25. The greatest increase in rheology index came from the low molecular weight HEC.

In conclusion, air knife coating formulations have a propensity to rib. A small rheology index of less than 0.25 is an indicator towards ribbing. The reduced rheology index is a function of the solids content within air knife formulations. In order to reach the rheology index of 0.25 or greater, it is recommended that other factors within the formulation, such as the binder or pigment, be changed along with the viscosifier.

12-10-97

Introduction:

The coating application process is an area of great concern for most mills that produce a coated media. During the roll application of the coating onto the sheet, the fluid that is passed to the sheet from the roll goes through a process known as film splitting. Film splitting is the mechanism for the transfer of the fluid from the application roll to the sheet. Instead of smoothly transferring onto the sheet, the film splits away from the roll and then onto the sheet. This splitting causes a ribbing effect on the application roll, which aids in reducing the effective transfer of the coating to the substrate. Without effective transfer, the ability of the coating to level is hindered. The result of these effects causes an unacceptable striation of the coating in the machine direction on the sheet.

Ribbing is a function of the application process and the rheology of the coating. The application or mechanical process includes the application type. Coating can be applied by reverse roll application, forward roll application, and multiple roll application, to name a few. The type of application can have a dramatic affect on the propensity to cause ribbing based on the applicator roll size, the speed of the applicator rolls, and the gap setting of the applicator roll. The rheology of the coating also plays an important role in the onset of ribbing. It has been shown that the rheology index helps determine the potential for ribbing. The rheology index is the ratio high shear viscosity (HSV) / low shear viscosity (LSV) (3). As the rheology index increases, the propensity for ribbing decreases, which increases the transfer and leveling effects of the coating, yielding better coating coverage. It has been shown that 'good' transfer and leveling properties are achieved at a rheology index above 0.25 (3). This means that acceptable transfer and leveling properties are achieved at a high HSV and a low LSV.

The purpose of this thesis is to analyze the coating rheology on the K-1 board machine at

Fort James (FJ) in Kalamazoo, MI. The K-1 machine is a state of the art, 100% recycled board machine that produces board for companies such as Kellogg and Proctor and Gamble. K-1 was built in 1992 and is configured with three head boxes that produce the different plies. The dry end of the machine utilizes a dual coating system. The first coat is a bar coating used to help smooth the surface of the sheet and provide a good base for the air knife coating. The second coat is an air knife formulation designed for brightness, sheet coverage, and printability.

The initial focus was to utilize the dynamic stress simulator in the printing department to test the effect of low shear viscosity on the air knife coating. In addition, the high shear viscosity was evaluated using the Hercules viscometer. Once the present coating was characterized, alternate thickeners were introduced to try and alter the rheology index. The alternate thickeners were carboxymethyl cellulose (CMC), and hydroxyethyl cellulose (HEC), both at low and medium molecular weights. These thickeners have different chemical functionality and formed different structures within the coating. Next, each coating sample was tested to determine the low and high shear viscosity. The rheology index for each sample was then compared with the rheology index of the original air knife coating. If an optimum rheology index could be achieved, the coating would be resistant to problematic ribbing, which would yield better transfer and leveling properties.

Goals:

The goal of this thesis was to determine the rheological affect of the coating on predictive ribbing behavior by changing the viscosifier (thickener) in the air knife coating formulation. Two alternate viscosifiers were used at different molecular weights and varying concentrations.

Objectives:

It has been shown that the rheological index is an indicator of ribbing and film split on the reel (3). This thesis proposes:

- Use medium and low molecular weight CMC at different concentrations to change the rheology index.
- Use medium and low molecular weight HEC at different concentrations to change the rheology index.
- Show that the rheology index can be altered simply by changing the viscosifier, which will theoretically show that the effects of ribbing can be manipulated by means of the coating rheology.

Background:

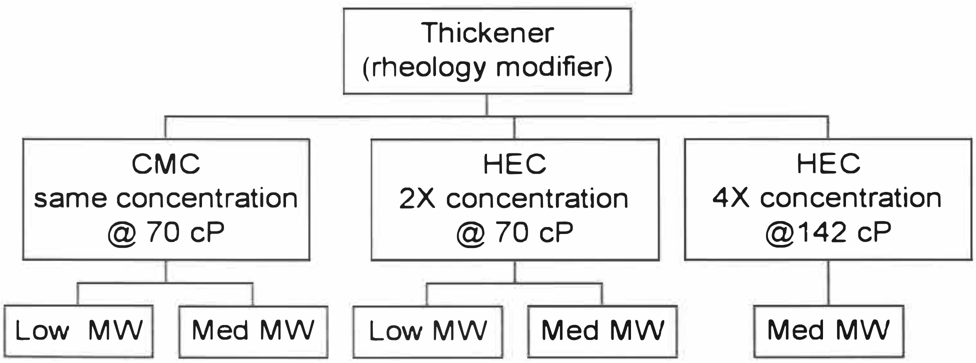
In the application of traditional latex based coatings a striation pattern occurs which is parallel to the direction of coating (3). This is a problem common to all coating applications for all coating dependent industries. Most of the time the problem is dealt with in a physical manner such as varying roll speeds or using different coating application techniques.

The background for this specific thesis is fairly limited. Many of the articles dealt with reverse roll coating (RRC)(2) and coating with Newtonian fluid (3). Reverse roll coating articles do not directly pertain to this thesis because FJ coating application is not RRC and because most RRC applications are at machine speeds of less than 500-ft/min (1). The machine speed for K-1 ranges from 1000 - 1200 ft/min.

Methods:

Four different coating formulations were made using the alternate viscosifiers. The following flow chart shows the thickener used and the concentration of the thickener. The CMC sells under the trade name of CMC-7L and CMC-7M for low and medium molecular weights respectively. Also, the HEC sells under the trade name of HEC-250LR and HEC 250-GR for low and medium molecular weights respectively.

Experimental Design



The original air knife coating produced a Brookfield test @ 70 cP of 0.15 pph (Appendix 3). The CMC coating was made and tested at 0.15 pph for the low and medium molecular weights. The HEC was first made at the original concentration of 0.15 pph but its Brookfield viscosity measured at 30 cP for low and medium molecular weights. It is important for comparison that the initial Brookfield viscosity be the same as the original air knife viscosity. The initial Brookfield measurements were tested at 60 rpm using the #2 spindle. For this reason the low Brookfield viscosity HEC coating was removed from the experimental design. Next, the HEC concentration was increased to match the 70-cP Brookfield viscosity range. This resulted in doubling the concentration of the HEC to 0.60 pph. Finally, an additional batch of HEC medium molecular weight coating was prepared at 4X concentration with a Brookfield viscosity of 142 cP.

After the coating formulations were prepared they were subjected to low and high shear viscosity testing. The Scientific Rheopectic viscometer was used to test for the low shear viscosity. A double couette geometry was utilized to test the dynamic frequency sweep, dynamic stress sweep, and a steady stress sweep. All coatings were pre-sheared at 50 dynes/cm² for 30 seconds and allowed to recover for 300 seconds before testing. The Brookfield viscometer was used to test the HSV. The HSV data was used to plot rpm vs. torque and apparent viscosity vs. shear rate.

Funding, Facilities, and Equipment:

The supplies for this thesis are listed below along with their origin or cost of purchase. In addition, the approximate time frame for testing is listed.

1) Base Coating	Supplied by Fort James	5) Dynamic stress simulator	Available in printing lab
2) CMC	Supplied by WMU	6) Double couette bob	Purchased by printing lab. @ $3200.00
3) HEC	Supplied by WMU	7) Coating make up and testing	15 – 20 hours
4) Hercules	Available in CLC lab	8) Problem preview and materials	20 – 25 hours

Results:

The results of this thesis are given in the following table.

	HSV	LSV	HSV/LSV	% Change
Air knife	6.6	94	0.070	
HEC-L	4.5	25	0.180	157.1
HEC-M	5.7	60	0.095	35.7
HEC-high	11.4	74	0.154	120.0
CMC-L	6.7	90	0.074	5.7
CMC-M	7.6	90	0.084	20.0

Discussion:

For graphical reference please see the appropriate appendix. The control for the graphical comparison is the test data from the original air knife coating sample. G' is a measure of the elastic portion of the coating. G'' is a measure of the viscous portion. The visco-elastic measurement is given as tan delta or G''/G'. The elastic (G') portion of the coating is referring to the solid like behavior in the coating system. The components within the coating formulation have charge functionality and therefore form a structure within the coating system. This structure causes the fluid to behave like a solid part of the time. For instance, as the fluid is put under shear the resistance of the coating fluid to move is due to the structure within the coating. Similarly, the viscous (G'') portion plays a role in the rheology of the system. The viscous component is the fluid like behavior of the coating system. Again, as shear is put into the system the elastic portion of the fluid is trying to resist flow, while the viscous portion is trying to allow flow. The resistance or ability of the coating to flow is a function of the strength and type of structure that is built within the coating. As the shear rate increases the structure begins to yield or breakdown and the fluid begins to flow. This is known as a shear thinning effect and is indicative of coating systems. An explanation of the following graphs will give a further description of the rheology of the coating formulation.

Appendix 1-A is a comparison of HEC at low and medium molecular weights with the control. In addition, the high concentration HEC is also compared. This graph is the measure of the amount of viscous structure that is built within the coating by the thickener. It is also a measure of the type of structure that is being built. The results indicate that the medium molecular weight HEC at the 2X concentration is significantly lower than the HEC-LR and the high concentration HEC-GR. This means that the HEC medium molecular weight did not build as much structure as the other HEC samples or the original air knife coating. In addition, the upward slope indicates that the structure is actually due to polymeric entanglement and may not be a complete measure of the bonding structure.

Appendix 1-B is a similar comparison of the HEC thickeners with the control. This measurement is of the elastic portion of the coating formulation. This reinforces the previous data and shows that the HEC medium is significantly lower in the elastic structure of the coating. This further shows that the polymers within the coating may be entangled, although the upward slope is much less pronounced.

Appendix 1-C is the visco-elastic measurement of the HEC modifiers. The visco-elastic data is a measurement of the ratio of the viscous portion / elastic portion. The visco-elastic behavior is the expected result based on the viscous and elastic data of the previous two graphs.

Appendix 1-(D,E, F) is a comparison of the CMC thickeners with the control. This data shows that there is not much difference in the viscous coating structure when the original thickener is replaced with the low or medium molecular weight CMC. The small upward slope is too low in the order of magnitude to conclude that there is polymeric entanglement. A similar comparison of the CMC with the control for the elastic measurement of the coating fluid is also shown. As with the viscous portion there was very little difference in the elastic structure with the addition of CMC.

The dynamic frequency testing was measured to give a basis for the structural integrity of each of the coating formulations. These tests were further used to back up other testing such as the steady stress sweep. If there was a great deal of structure then the coating could have a large shear thinning effect. The dynamic frequency sweep information is used to validate further findings when testing the viscosity.

The next set of graphs is measuring the dynamic stress sweep. This comparison shows that as stress is added to a coating system there is a point where the line begins to drop. This drop point is called the yield point. The yield point is where the coating structure begins to break down and the coating begins to flow. The 'y' axis gives the amount of structure within the coating while the 'x' axis shows how strong the structure is in terms of how much stress it took for the structure to begin to yield.

Appendix 1-(G,H) is the dynamic stress sweep for the HEC coatings. The control and HEC at the high concentration started with the same amount of structure and both failed around 5 dyne/cm^2. The medium molecular weight started with less structure and failed at a stress of @1.367 dyne/cm^2. The low molecular weight HEC had the least amount of structure and failed at the lowest stress of 0.488 dyne/cm^2.

Appendix 1-(I,J) is a measure of the elastic portion of the dynamic stress sweep, and the graph shows that failure occurred at @ 3.0 dyne/cm^2 for the control and high concentration HEC.

The medium molecular weight and low molecular weight HEC had a yield point of 1.367 dyne/cm^2 and .488 dyne/cm^2. It should be noted that the yield point for the G' and G'' for the low and medium molecular weights were the same for the elastic and viscous measurements. The high concentration HEC and control showed a difference in their elastic and viscous measurements.

Appendix 1-(K,L) shows the measure of the steady stress sweep for the viscous and elastic components of the different concentrations and different molecular weights. The HEC comparison shows that each level of thickener had a different zero shear viscosity. It also showed that they each had the same shear thinning behavior. The amount of change per increase in rate is almost equal for each of the thickener levels. The increase in viscosity for each of the coatings at the higher shear rates is the point when the dynamic stress simulator reached overload for the system. The Hercules high shear viscosity was tested to see if the overload point was actually the high shear value. The CMC comparison shows that the coatings had almost the same initial viscosity. As the shear rate increased the shear thinning effect was almost identical. This indicates that after the yield point the behavior of the fluids was basically the same.

Appendix 1-(M,N,O,P). The HEC and CMC coatings were compared to the control using the Hercules viscosity tester. For each coating the rpm vs. torque, and the apparent viscosity vs. shear rate were plotted. The HSV values were taken from the raw data section at a shear rate of 10000 sec^{-1}. The desired rheology index that was reached for coatings with good transfer and leveling characteristics was calculated at 10000 sec^{-1} (3). The result of these graphs reinforces the HSV values, and indicates the behavior of the coating fluid beyond the shear stresses of the machine. Each of the coating formulations show a breakpoint where the viscosity begins to increase. According to the operating manual these are areas of hydrodynamic instability and are not considered accurate data. The Reynolds number for this region was calculated and shown to be in the region of vortical flow, which is above 41.3 (Appendix 2). This indicates that at these shear rates the fluid was unstable due to the operating parameters.

Conclusions:

The HEC-low molecular weight formulation showed the highest rheology index. This index was still lower than the desired 0.25 that is needed to optimize the appearance of the coating on the sheet. The low shear viscosity was low enough to be effective, but the HSV needs to be high to accommodate the rheology index.

At the control HSV of 6.6 cP, the LSV would need to be 24 cP to reach the desired rheology index. In addition, at the control LSV of 94 cP, the HSV would need to be 27 cP. It may be possible to reach 27 cP under high shear conditions. In order to keep the structure intact during these shear conditions it would require changing more than just the thickener. In addition, it is unlikely to have a HSV of 6.6 and a LSV of 24. If the rheology index is calculated the coating would impart good coverage. However, at these viscosities it would be unlikely that good coverage would be accomplished do to the limitation of the solids to reach the low viscosities.

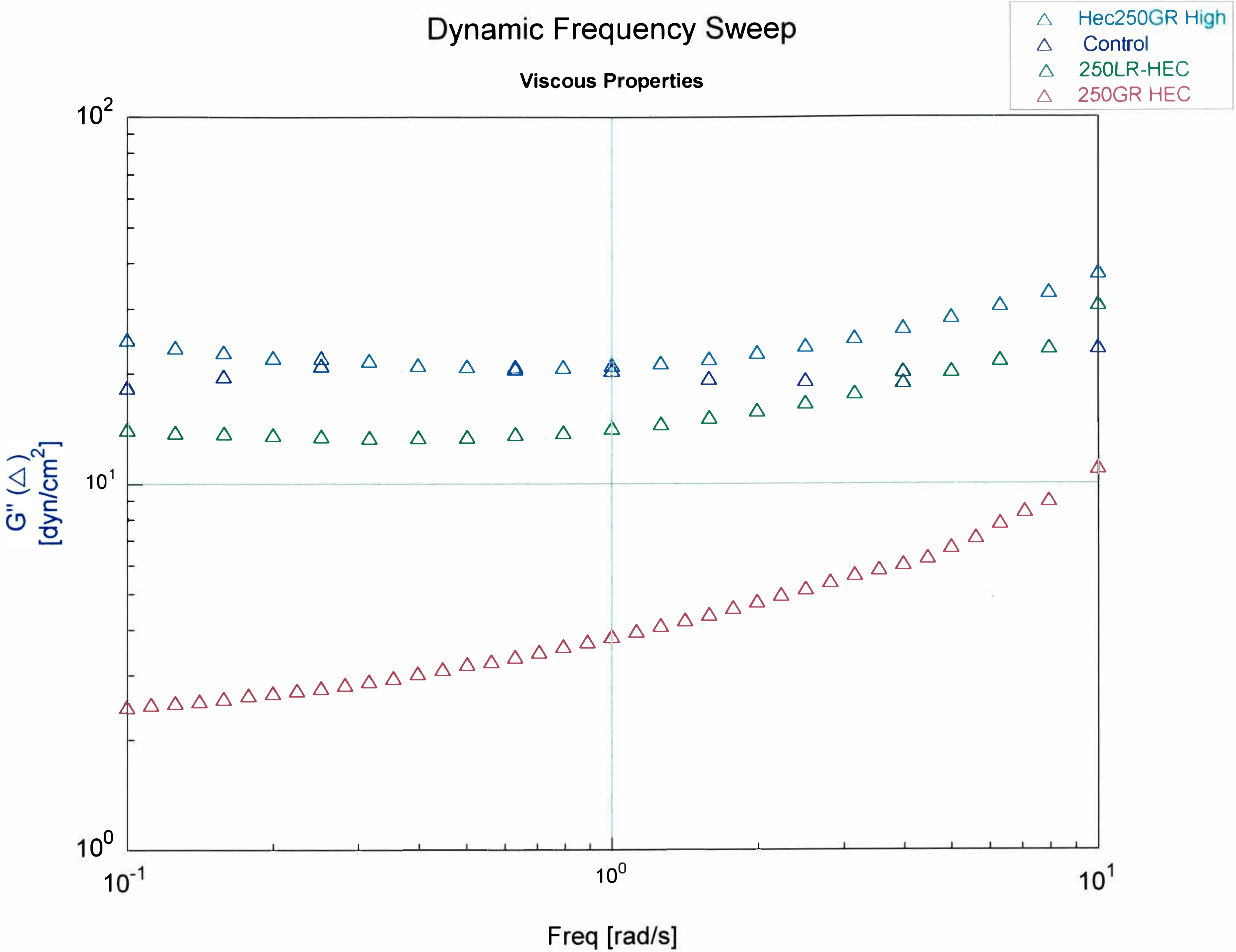
The reason that it is difficult to achieve a rheology index of greater than 0.25 is because of the low coating solids. The air knife formulation needs a lower solids content to achieve good leveling produced by the air knife. Therefore air knife coatings have a propensity to rib. This propensity to rib hinders the ability of the coating to impart good transfer and leveling properties.

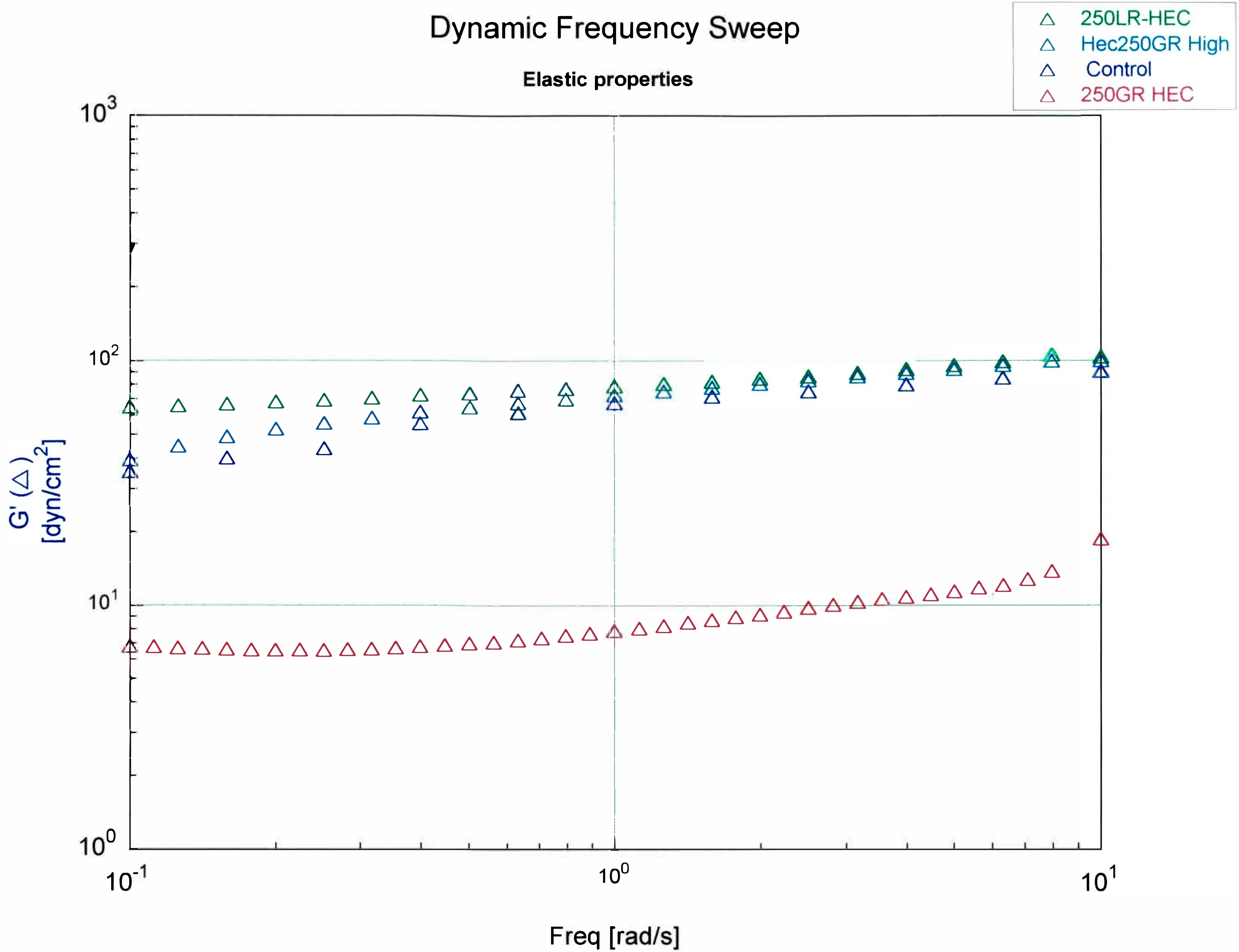
The result of this work leaves many avenues untouched. Future work could include altering the pH of the system, manipulating the type of binder used, or changing the addition sequence of the coating to build a stronger structure. Another consideration may be to look at changing the type of coating application. For instance, if a rheology index of 0.25 proves to be a legitimate target for increasing coating appearance, it may be possible to obtain that by replacing the air knife system with a different system. An additional hindrance of the air knife system is its limitation with respect to speed. In order to increase machine speed and increase coating appearance, it may be necessary to apply the topcoat with a rod coater. Rod coaters run at higher solids and it would be easier to achieve a rheology index of 0.25 or greater.

1-A

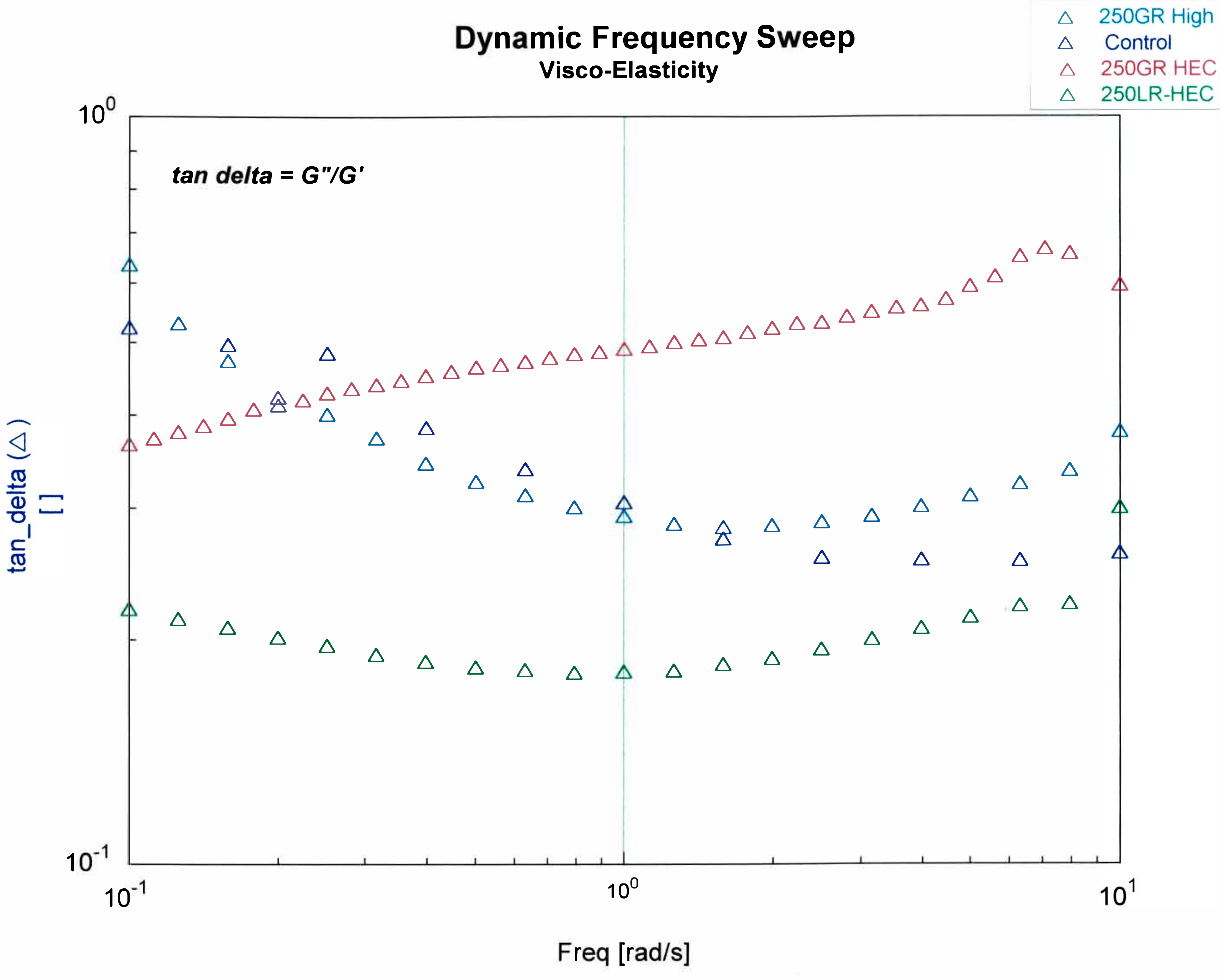
Dynamic Frequency Sweep

Viscous Properties

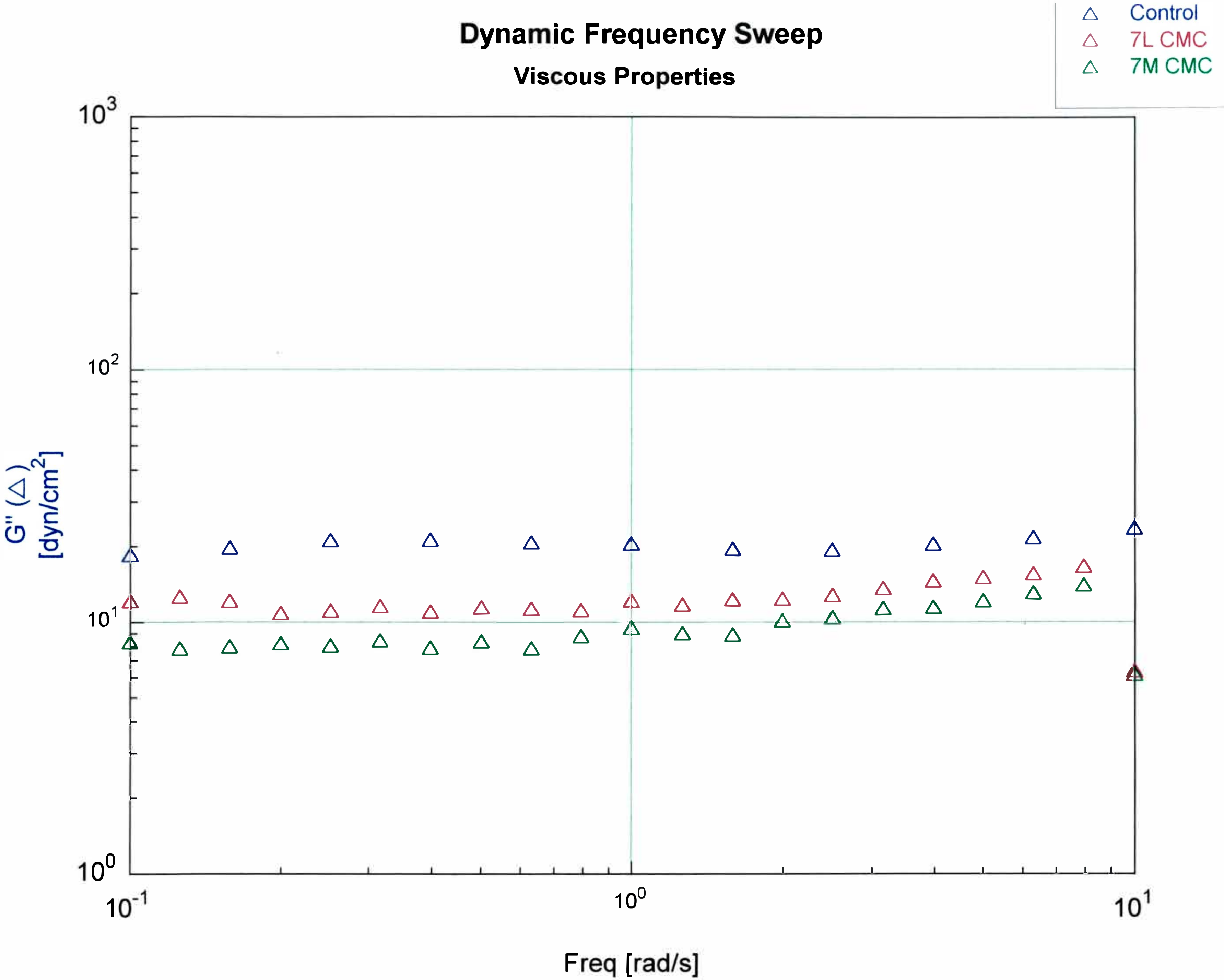



Dynamic Frequency Sweep
Elastic properties
250LR-HEC
Hec250GR High
Control
250GR HEC
G' (△) [dyn/cm²]
10³
10²
10¹
10⁰
10⁻¹
10⁰
10¹
Freq [rad/s]

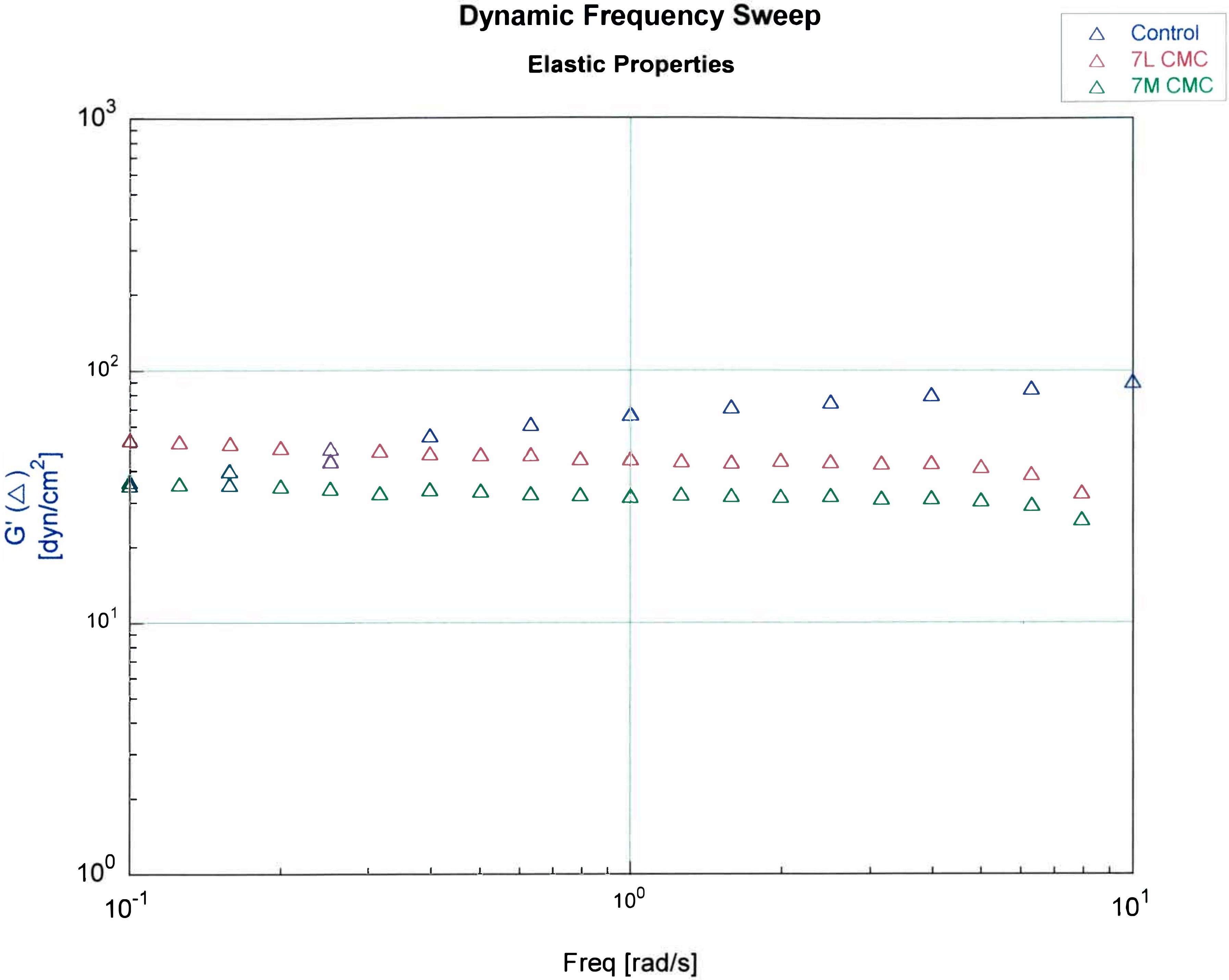
B


Dynamic Frequency Sweep
Visco-Elasticity
250GR High
Control
250GR HEC
250LR-HEC
tan delta = G"/G'
tan_delta (Δ)
[ ]
10^0
10^{-1}
10^{-1}
10^0
10^1
Freq [rad/s]

C

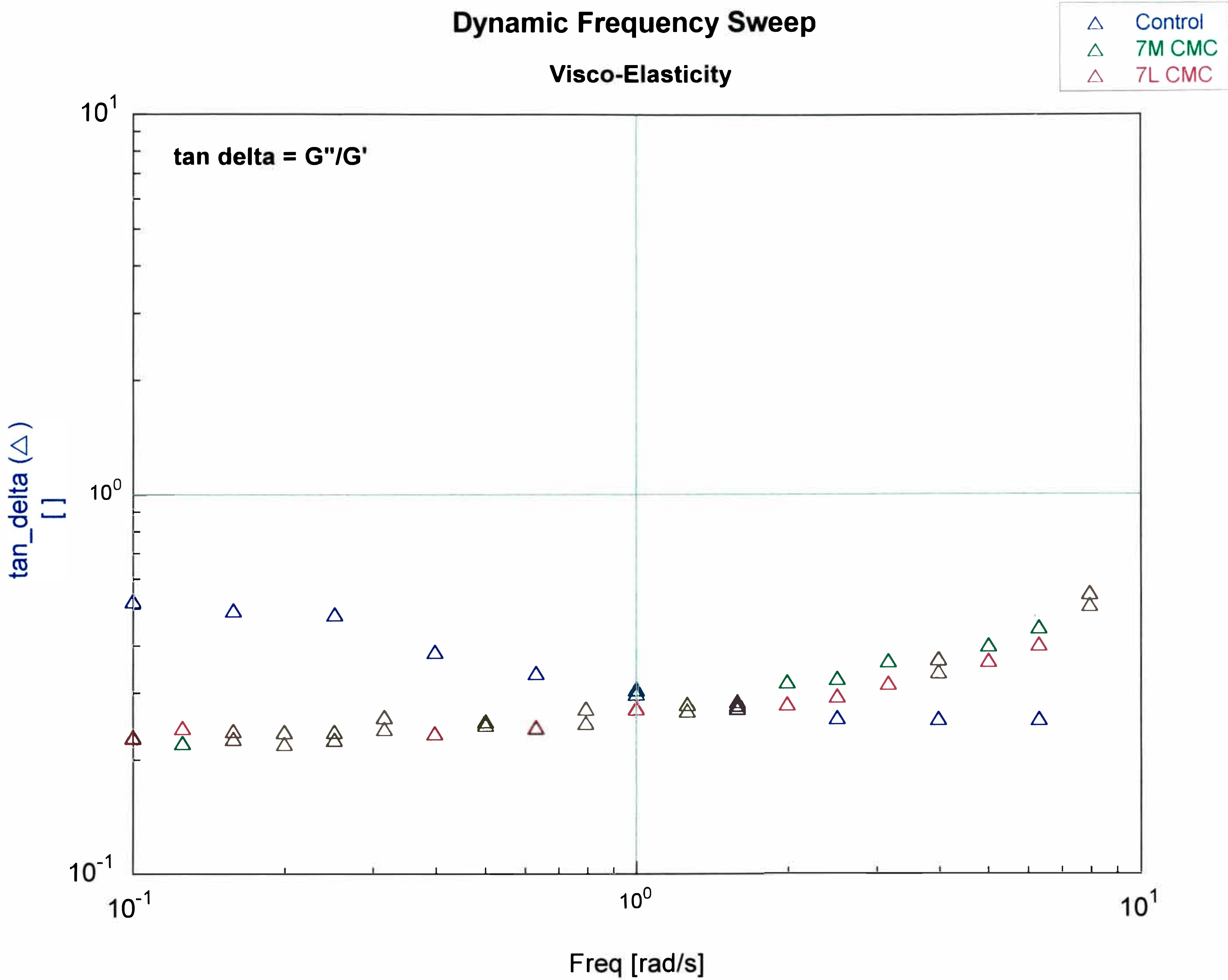

Dynamic Frequency Sweep
Viscous Properties
Control
7L CMC
7M CMC
G" (△) [dyn/cm²]
10³
10²
10¹
10⁰
10⁻¹
10⁰
10¹
Freq [rad/s]

D

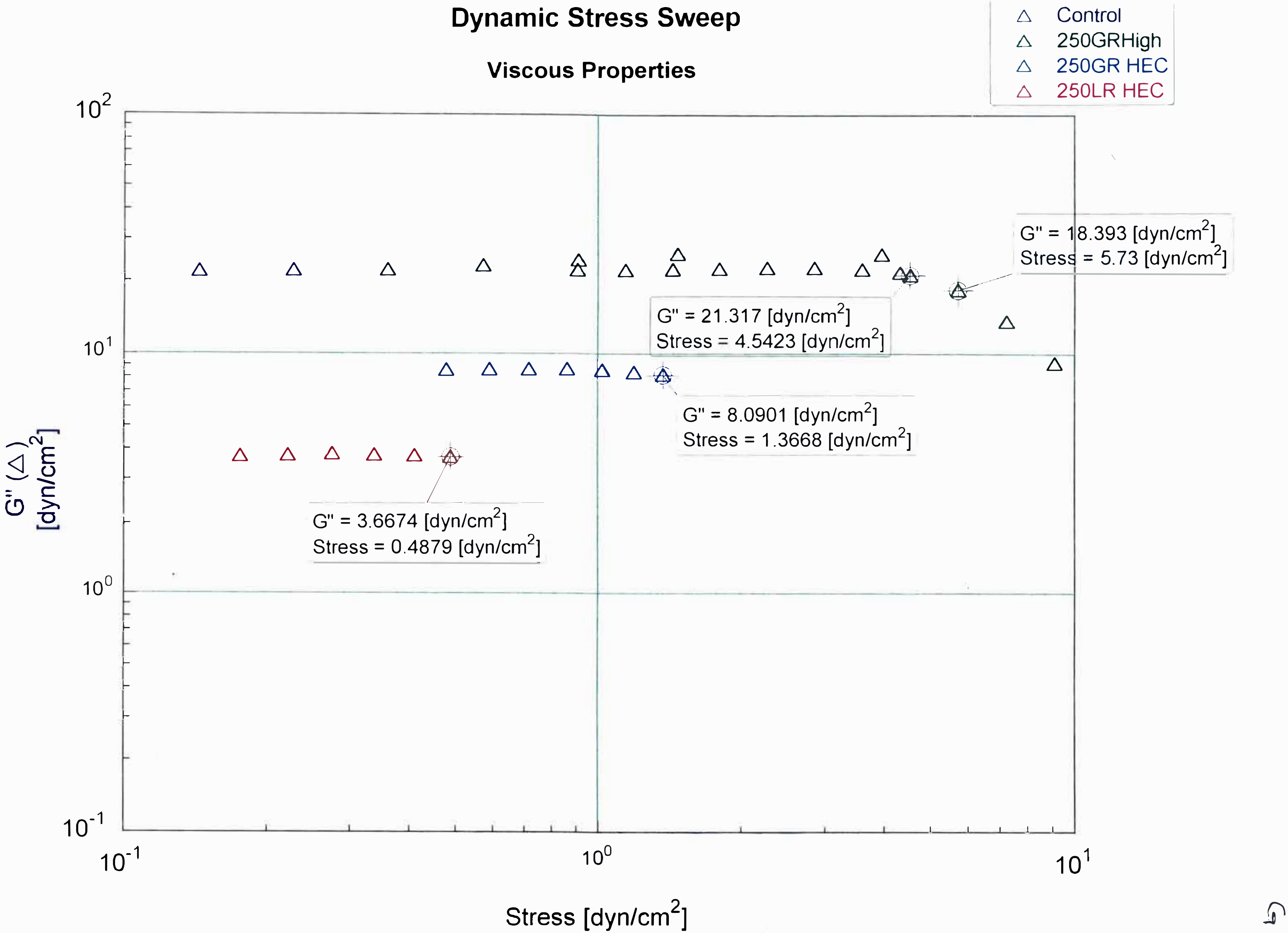


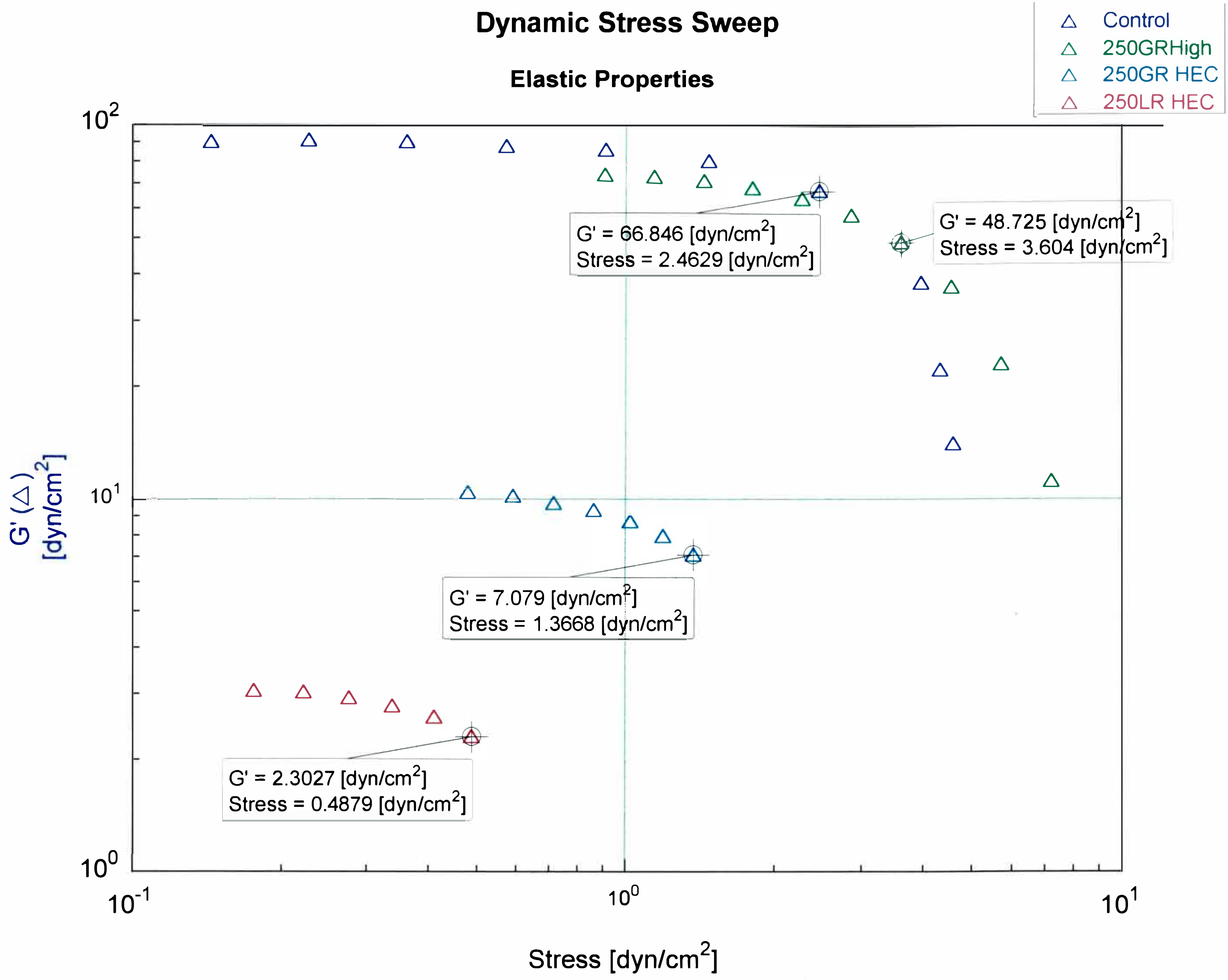
Dynamic Frequency Sweep
Elastic Properties
Control
7L CMC
7M CMC
G' (△) [dyn/cm²]
Freq [rad/s]

m

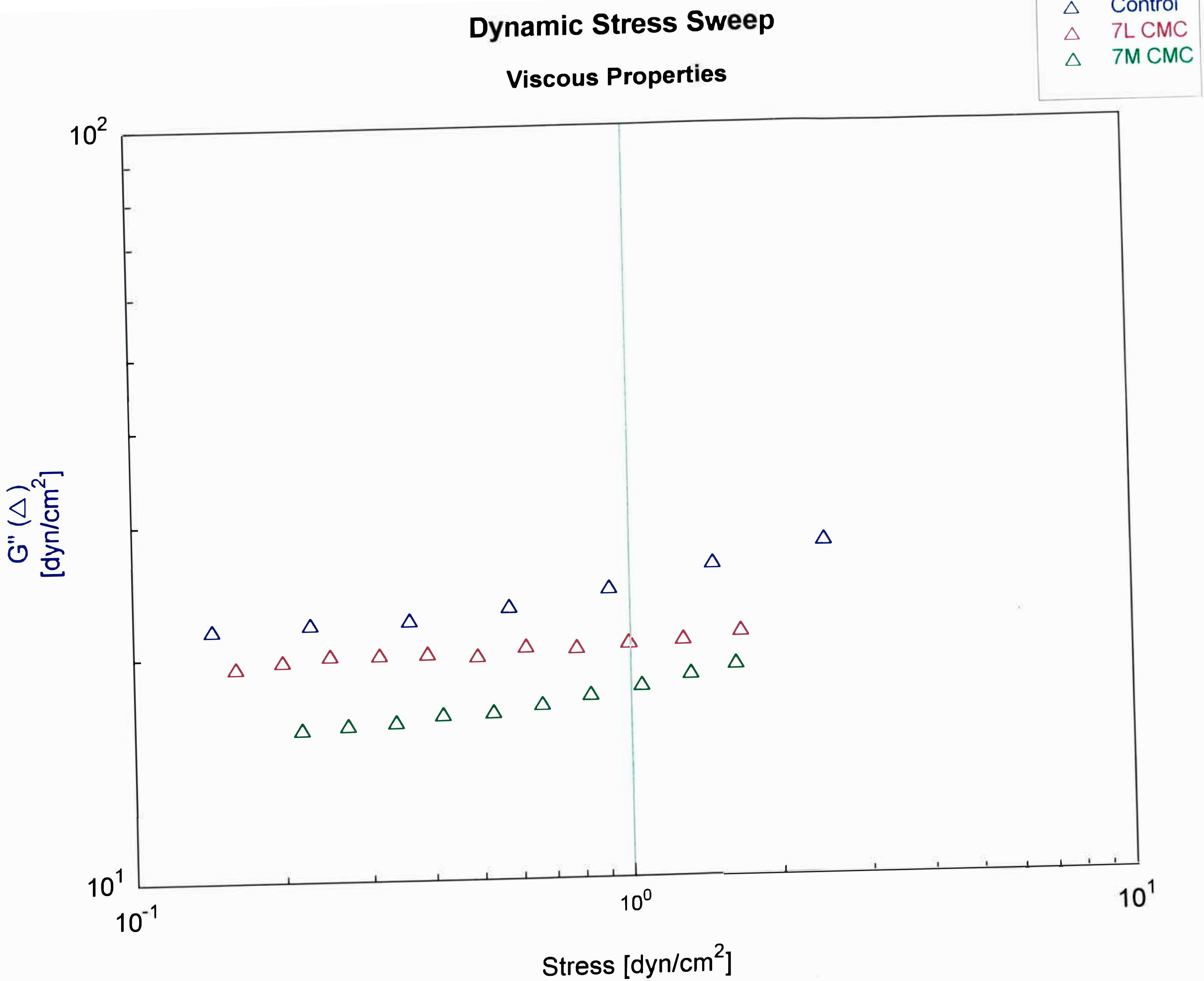

Dynamic Frequency Sweep
Visco-Elasticity
Control
7M CMC
7L CMC
tan delta = G"/G'
tan_delta (△)
[ ]
10^1
10^0
10^-1
Freq [rad/s]

F

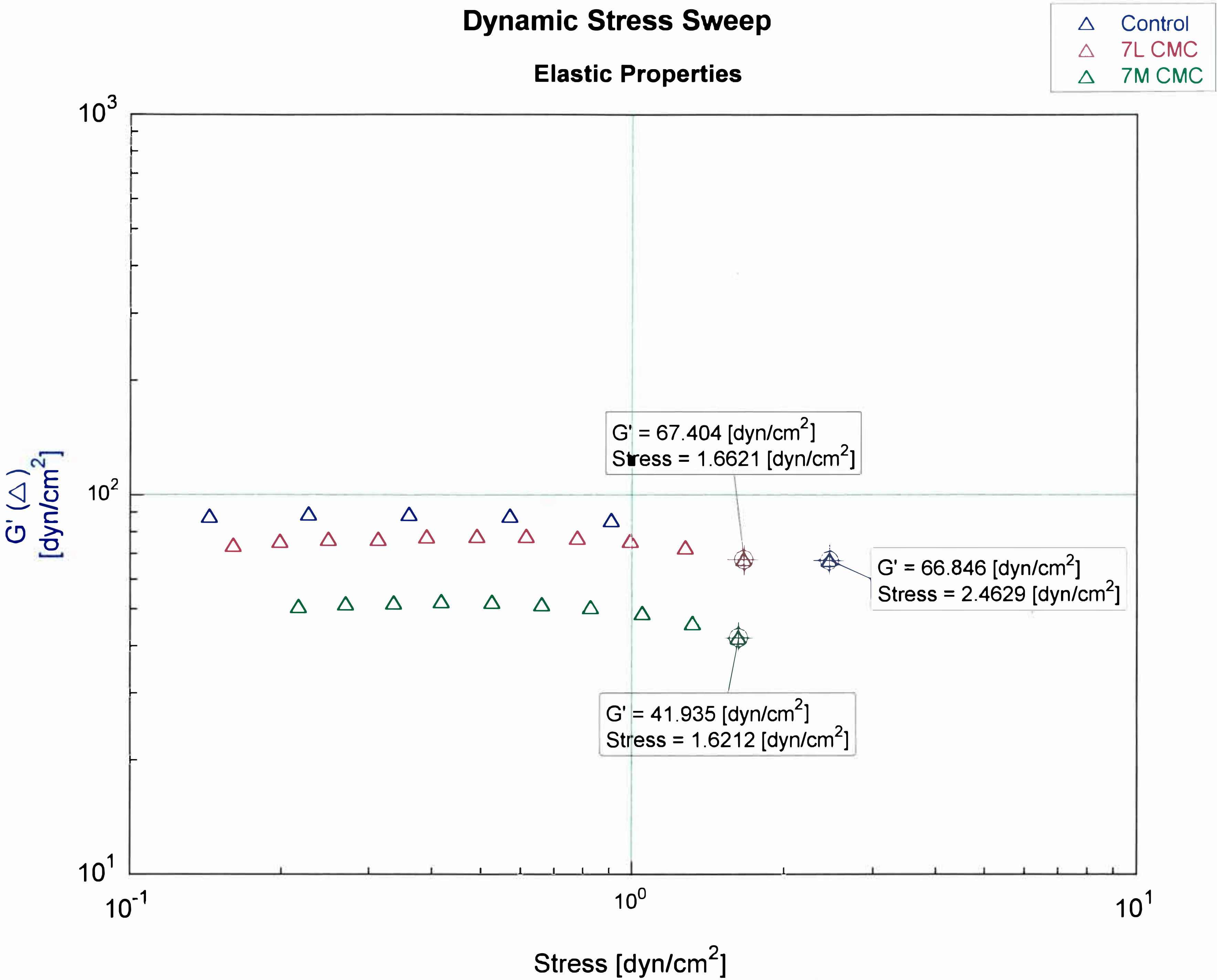

Dynamic Stress Sweep
Viscous Properties
Control
250GRHigh
250GR HEC
250LR HEC
G" = 18.393 [dyn/cm2]
Stress = 5.73 [dyn/cm2]
G" = 21.317 [dyn/cm2]
Stress = 4.5423 [dyn/cm2]
G" = 8.0901 [dyn/cm2]
Stress = 1.3668 [dyn/cm2]
G" = 3.6674 [dyn/cm2]
Stress = 0.4879 [dyn/cm2]
G" (△) [dyn/cm2]
Stress [dyn/cm2]
10^2
10^1
10^0
10^-1
10^-1
10^0
10^1



Dynamic Stress Sweep
Elastic Properties
Control
250GRHigh
250GR HEC
250LR HEC
10^2
10^1
10^0
10^{-1}
10^0
10^1
G' (△) [dyn/cm^2]
Stress [dyn/cm^2]
G' = 66.846 [dyn/cm^2]
Stress = 2.4629 [dyn/cm^2]
G' = 48.725 [dyn/cm^2]
Stress = 3.604 [dyn/cm^2]
G' = 7.079 [dyn/cm^2]
Stress = 1.3668 [dyn/cm^2]
G' = 2.3027 [dyn/cm^2]
Stress = 0.4879 [dyn/cm^2]

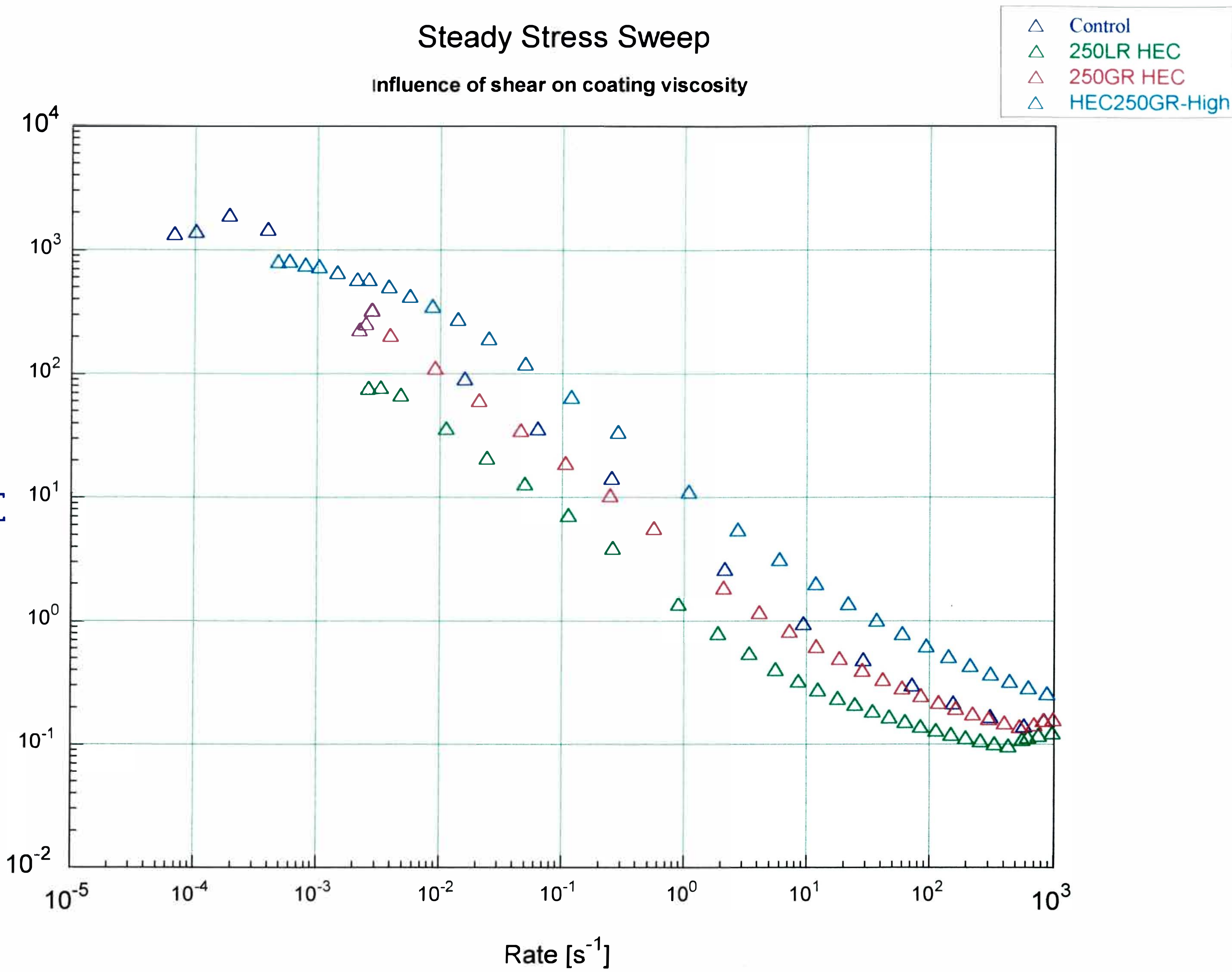


Dynamic Stress Sweep
Viscous Properties
Control
7L CMC
7M CMC
10^2
10^1
G'' (△)
[dyn/cm²]
10^{-1}
10^0
10^1
Stress [dyn/cm²]

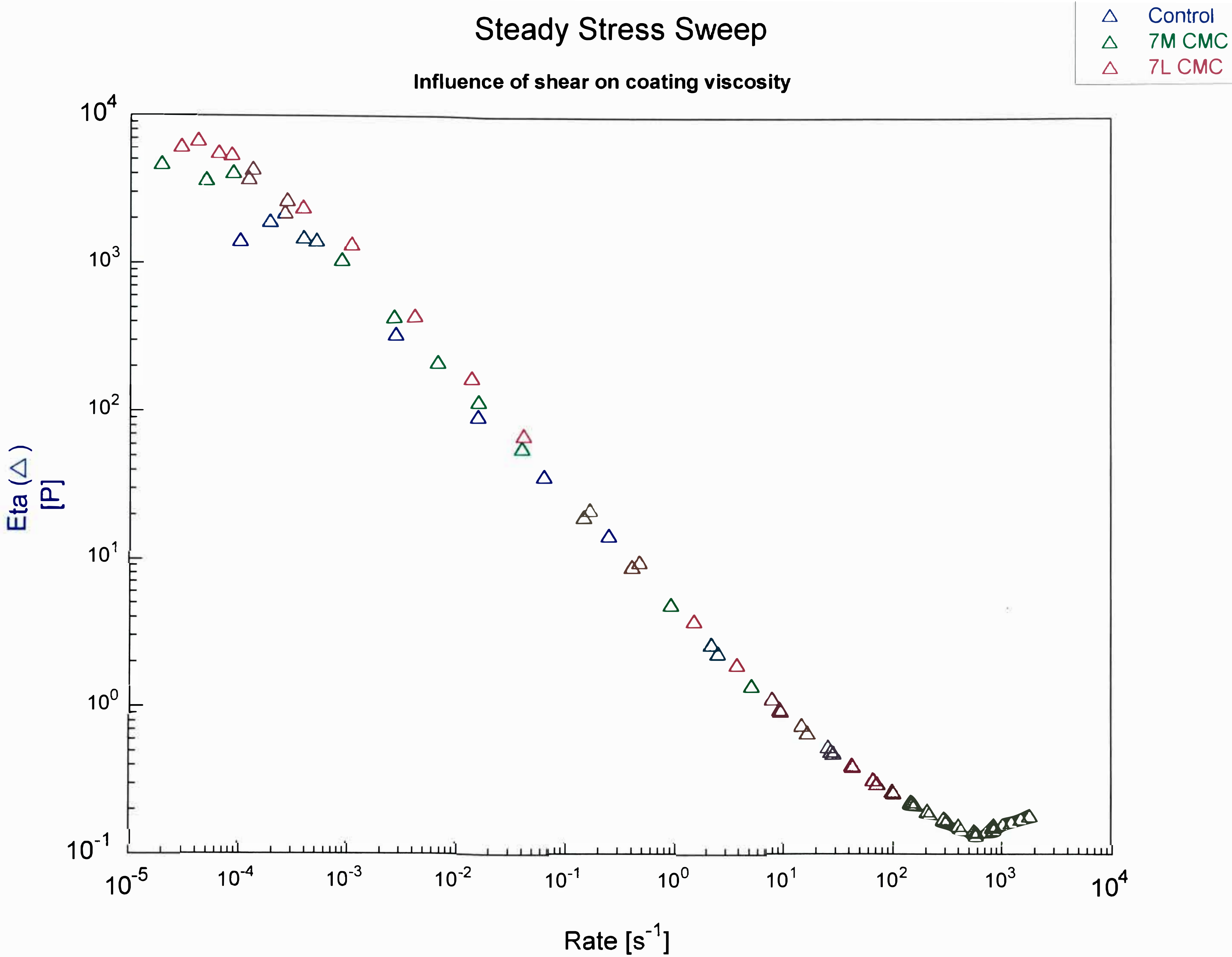


Dynamic Stress Sweep
Elastic Properties
Control
7L CMC
7M CMC
G' = 67.404 [dyn/cm2]
Stress = 1.6621 [dyn/cm2]
G' = 66.846 [dyn/cm2]
Stress = 2.4629 [dyn/cm2]
G' = 41.935 [dyn/cm2]
Stress = 1.6212 [dyn/cm2]
G' (△) [dyn/cm2]
Stress [dyn/cm2]
10^3
10^2
10^1
10^-1
10^0
10^1

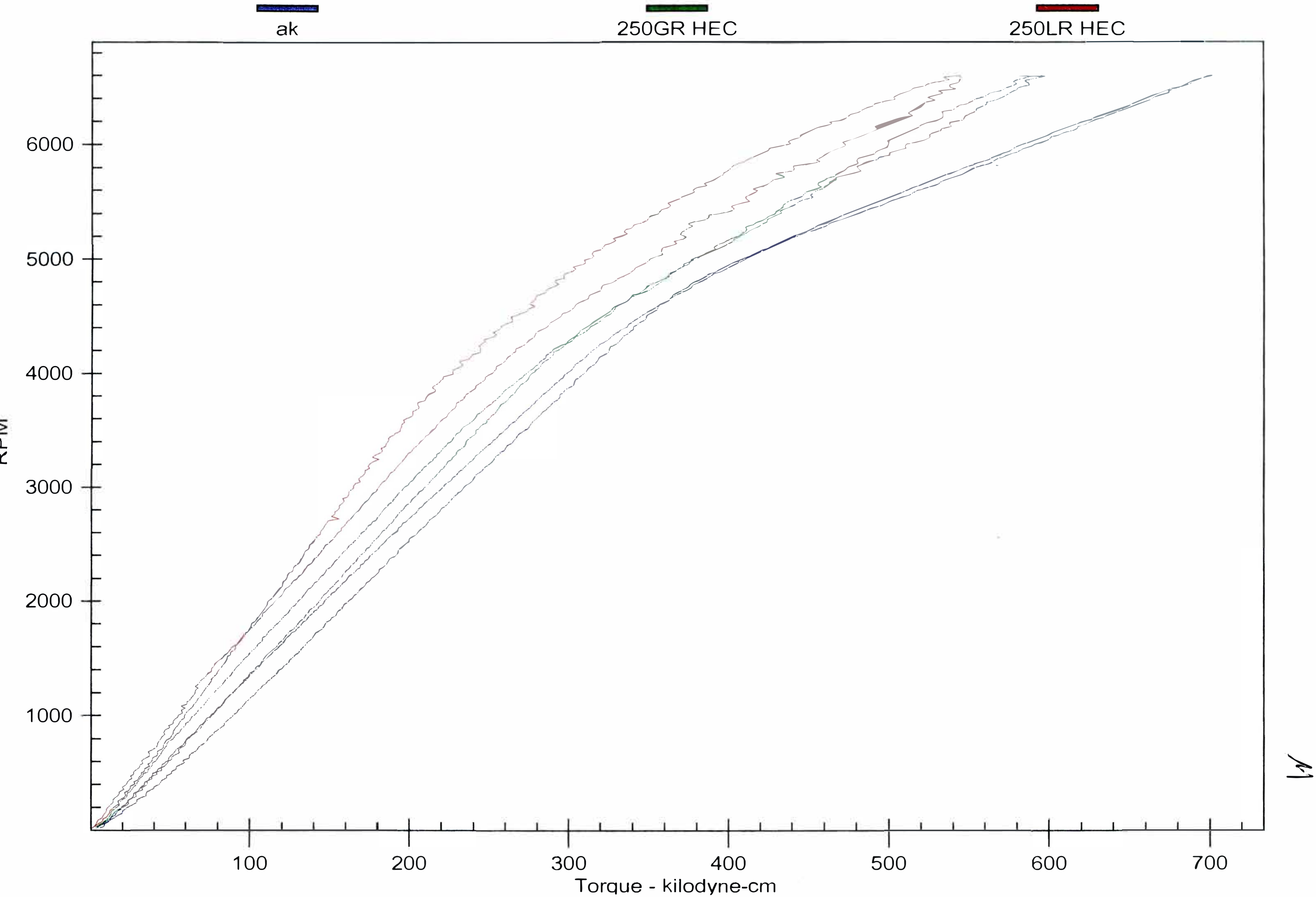
4



Steady Stress Sweep
Influence of shear on coating viscosity
Control
250LR HEC
250GR HEC
HEC250GR-High
Eta (△) [P]
Rate [s^-1]
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3


Steady Stress Sweep
Influence of shear on coating viscosity
Control
7M CMC
7L CMC
Eta (△)
[P]
Rate [s^-1]
10^4
10^3
10^2
10^1
10^0
10^-1
10^-5
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
10^3
10^4

HECCOMP.VIS Bob:E RPM:6600 Spring:100



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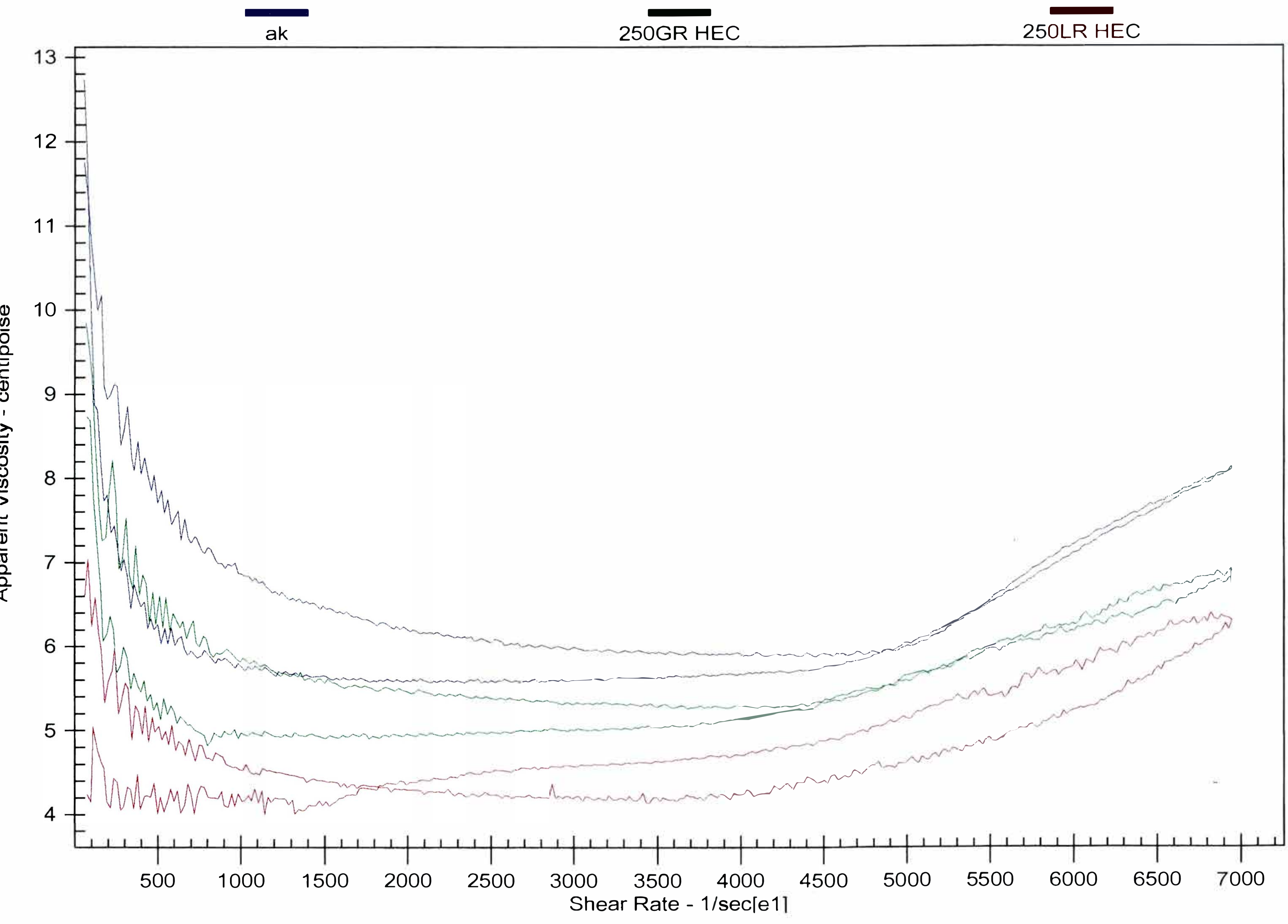
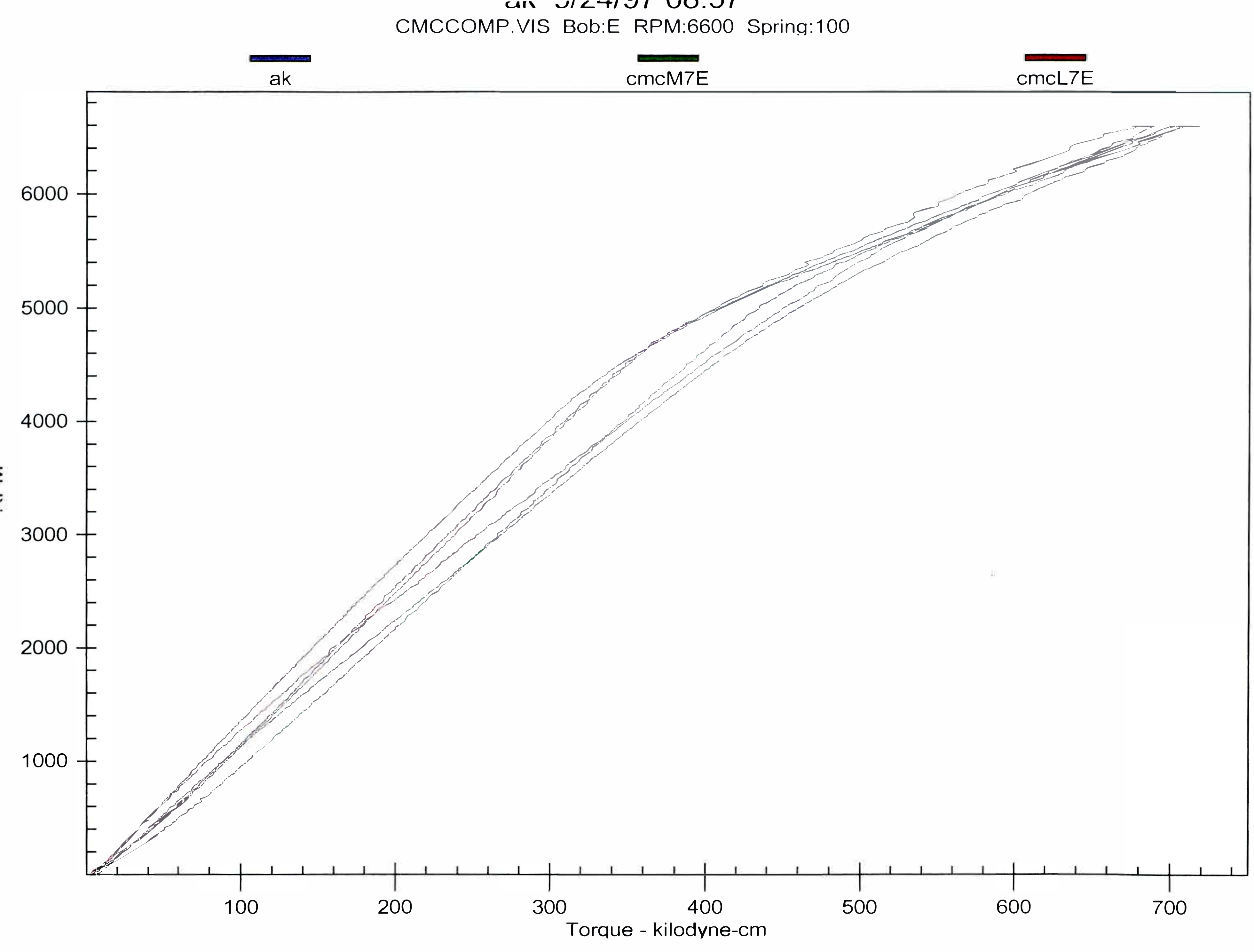
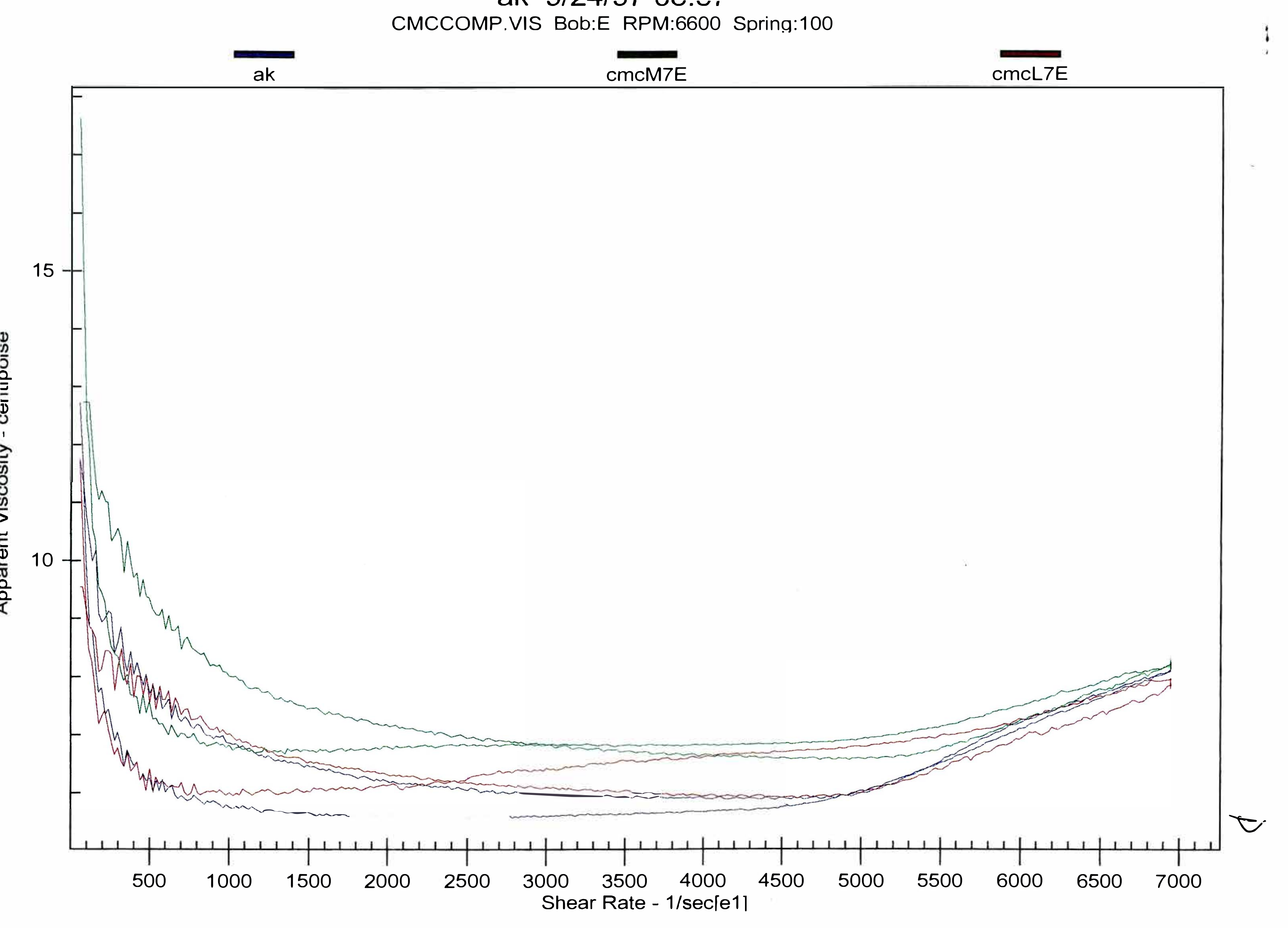
HECCOMP.VIS Bob:E RPM:6600 Spring:100




ak 5/24/97 08:57
CMCCOMP.VIS Bob:E RPM:6600 Spring:100
ak
cmcM7E
cmcL7E
1000
2000
3000
4000
5000
6000
100
200
300
400
500
600
700
Torque - kilodyne-cm



CMCCOMP.VIS Bob:E RPM:6600 Spring:100
ak
cmcM7E
cmcL7E
15
10
Apparent Viscosity - centipoise
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
Shear Rate - 1/sec[e1]

Reference:

(1) Coyle, D.J., Macosko, C.W., Scriven, L.E., "Reverse Roll Coating of Non-Newtonian Liquids", J. Rheology 34, July 1990, v5, p615-636.

(2) Greener, J., Middleman, S., "Reverse Roll Coating of Viscous and Visceoelastic Liquids", Ind. Eng. Chem. Fundam., 1981, v20, p63-66.

(3) Matsuda, T., Brendley FJ., W.H., "Transfer and Leveling Processes and Rheological Design in Water-Borne Reverse-Roll Coating Systems", Journal of Coatings Technology Reprint

INTERFERENCES IN INTERPRETATION OF RHEOGRAMS

Proper interpretation of rheograms and calculation of apparent viscosity are valid only when all approximations defining planar Couette flow are satisfied. Erratic results may be obtained from either improper operation of the instrument or an indication that some reservations should be encountered, such as lower maximum shear rate for extremely viscous fluids. Although, in general, the Couette flow assumption pertains to testing fluids with a Hercules® Hi-shear viscometer, improper sample preparation and testing procedures can generate erroneous results. In addition, certain phenomena independent of material properties, such as hydrodynamic events or air entrainment during testing, may interfere with a measurement .

The scope of the following discussion is to show how some of these interferences can be identified and, sometimes, prevented or corrected. This does not mean to suggest that all kinds of interferences will be present in every viscometric test. Some features, like slipping and the associated air entrainment, represent characteristic properties of the fluid under consideration and should be reported as such since in practice such a fluid will also be unsatisfactory. In other words, the instrument in its way is indirectly indicating that a fluid may be problematic during its application or limited to its performance.

Vortical Flows

The curvilinear movement of fluid in the annular gap of HHSV induces three-dimensional hydrodynamic instabilities when the rotational speed of the bob increases beyond a critical value depending on gap dimensions and viscosity. At first, disturbed flows (resembling a stack of automobile tires stacked the one on top of the other) appear, termed Taylor vortices. These flows become periodic in time with single and double frequencies of oscillation at higher speeds Such hydrodynamic flow instabilities will eventually degrade to turbulence at even higher rotational speeds. Taylor vortices can sometimes be visualized on the air-fluid interface at the top endface of the bob during the course of a test.

Theoretically, onset of Taylor vortices depends on the following criterion for the modified Reynolds number (Re_m) in Couette flows:

$$Re_m = \left(\frac{(rpm)\,\rho\, R_1 X_0}{9.55\,\eta}\right)\sqrt{\frac{X_0}{R_1}} \angle 41.3 \qquad (4)$$

where X_0 is the annular gap in cm and ρ the density of the fluid in gm/cc. The onset of vortical flows constitutes an interference as the total torque measured increases due to additional stresses introduced by hydrodynamic instabilities. However, this increase in torque does not relate to rheological properties of the fluid.

Development of vortical flows appears on the up curve of the rheogram as a distinctive point or sharp transition, referred to as "break point", above which the flowcurve shifts to greater viscosities since the slope of the drawn curve becomes steeper (Figure 12). Although rheograms with a break point can be recorded even when testing Newtonian fluids, confusion can be created when the fluid is non-Newtonian because

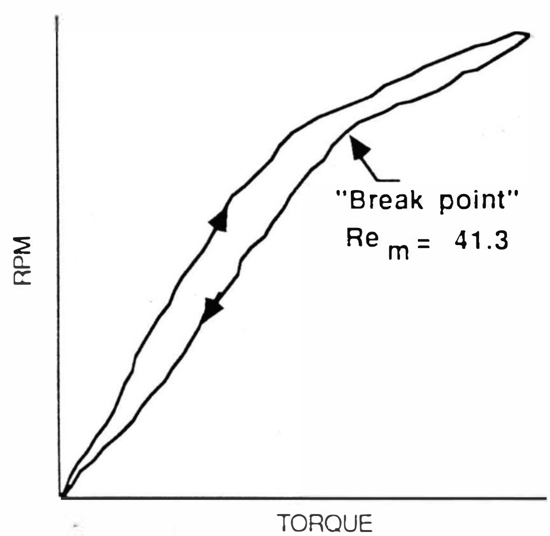


Figure 12

the shape of the flowcurve due to vortical flows resembles dilatant-type behavior. Utilizing the criterion listed in Eq. 4, however, it can be clearly determined if vortical flow interferes with a measurement by calculating the (theoretical) critical speed (RPM_{cr}) for onset of vortical flow as:

$$RPM_{cr} = \frac{41.3\,\eta}{G\rho} \qquad (5)$$

where viscosity is manipulated on the up curve at the break point and G is a geometrical factor depending on the size of the bob used:

$$G = \left(\frac{R_1 X_0}{9.55}\right)\sqrt{\frac{X_0}{R_1}} \qquad (6)$$

Numerical values of factor G are 1.63×10^{-3} (bob A), 0.42×10^{-3} (bob E), and 0.15×10^{-3} (bobs F and FF) which, when substituted in Eq. 5, provide an answer in rpm. If the calculated RPM_{cr} is close to the speed corresponding to the break point rpm from the rheogram, then increased viscosity in a flowcurve is a hydrodynamic effect and it does not represent dilatancy. The critical rotational speed for onset of Taylor vortices depends on gap width (smaller gaps require higher speeds for vortical flow to occur) and on the fluid properties, namely viscosity and density. The speed required for onset of unstable flow is proportional to viscosity. For example, flow interferences appear in rheograms with the E-bob geometry during a 0-4,400 rpm testing cycle when viscosity is less than 6.2 cps.

Temperature Effects

The approximation of isothermal conditions during an HHSV test is another assumption that warrants concern, as the thermodynamic temperature rise due to viscous heating generates a temperature gradient across the gap. Because the gaps utilized with HHSV are very small and the thermal conductivity of the metallic walls is

Appendix 3

MACHINE BATCH PREPARATION

MATERIALS	QUANTITY	UNITS
WATER	3111	Wet Lbs.
#1 CLAY	1752	Wet Lbs.
PREBLENDED CLAY	2532.1	Wet Lbs.
DISPERSANT	4.5	Wet Lbs.
DEFOAMER	6.3	Wet Lbs.
CALCINED CLAY	0.0	Wet Lbs.
TIO2	1040	Wet Lbs.
THICKENER	5.6	Dry Lbs.

MIX ON HIGH SPEED FOR 30 MINUTES.

REDUCE SPEED TO LOW AND ADD THE FOLLOWING:

LATEX	1576	Wet Lbs.
INSOLUBILIZER	80	Wet Lbs.

MIX FIVE MINUTES BEFORE PUMPING TO STORAGE.

Formula. No.9120

BATCH SIZE	(Wet Lbs)	10012
TARGET SOLIDS,%======>		45

Updated: 03:31 PM 03-Apr-97

CALCULATION OF BATCH

MATERIAL	% SOLIDS	DRY	WET
#1 Clay	70	1227	1752
Blended Clay	69	1747	2532
	50	0	0
TiO2	71.5	743	1040
Total Pigment ===>	45	3717	
Latex	50	788	1576
Weight (Sub Total) ===		4505	6901
Water Added to adjust total solids ===>			3111
Total Solids	45	4505	
Total Batch Size ======>			10012

To use this spread sheet enter variable in shaded cells.

BASIC FORMULATION

MATERIALS	pph
#1 Clay	33
Blended Clay	47
	0
TiO2	20
Latex	21.2
Thickener	0.15
Dispersant (wet/dry pigment)	0.12
Defoamer	0.17
Insolubilizer (wet/dry binder)	10.2
Other	0

Signature / Date