

(86) **Date de dépôt PCT/PCT Filing Date:** 2008/09/05
(87) **Date publication PCT/PCT Publication Date:** 2009/03/12
(45) **Date de délivrance/Issue Date:** 2016/01/26
(85) **Entrée phase nationale/National Entry:** 2010/03/05
(86) **N° demande PCT/PCT Application No.:** US 2008/075452
(87) **N° publication PCT/PCT Publication No.:** 2009/033060
(30) **Priorités/Priorities:** 2007/09/07 (US60/970,809);
2007/09/28 (US60/976,141); 2007/10/12 (US11/871,782)

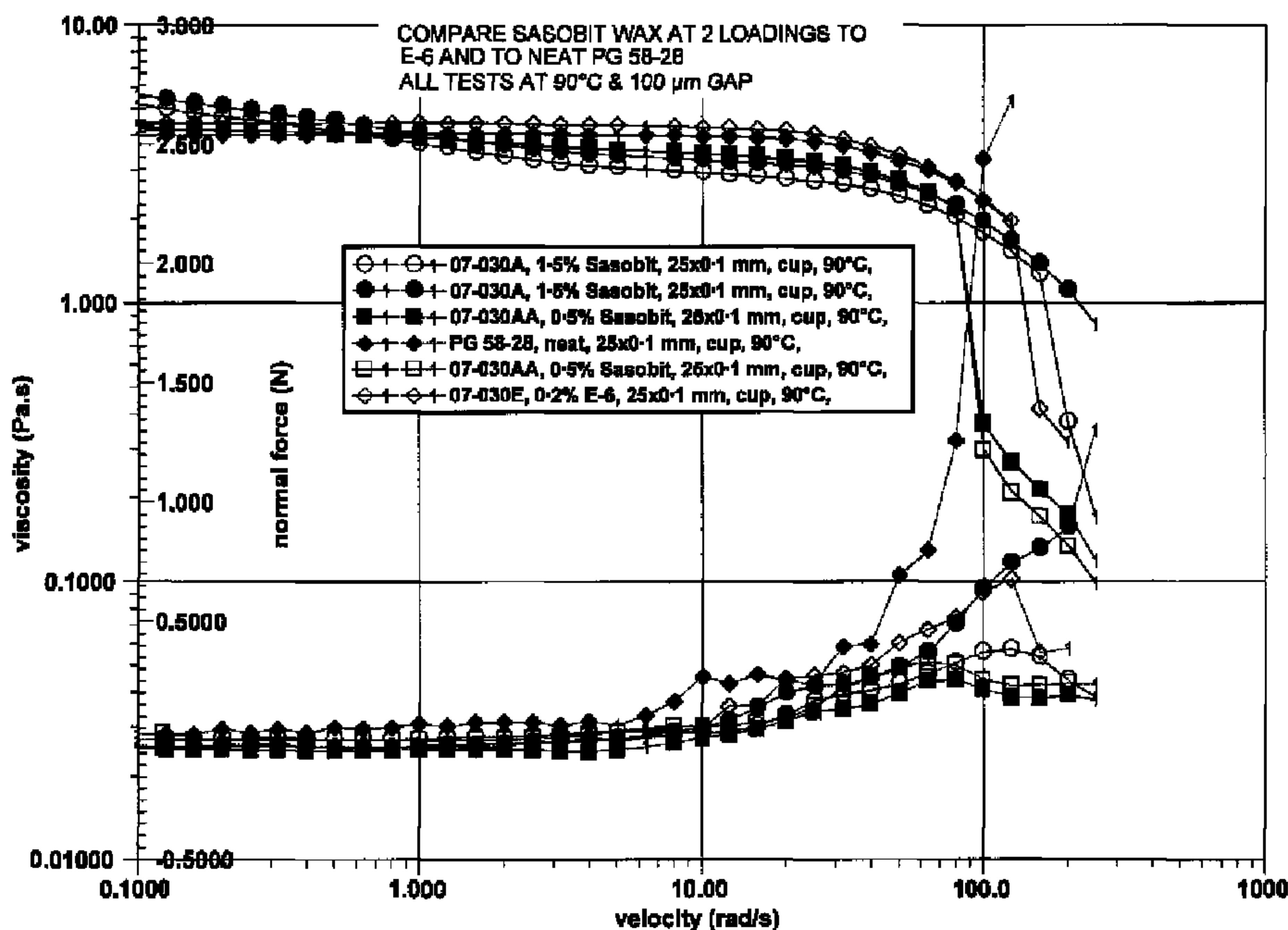
(51) **Cl.Int./Int.Cl. C08L 95/00** (2006.01),
E01C 7/00 (2006.01)

(72) **Inventeurs/Inventors:**
REINKE, GERALD H., US;
BAUMGARDNER, GAYLON L., US;
ENGBER, STEVEN L., US

(73) Propriétaire/Owner:
ALM HOLDING CO., US

(74) **Agent:** MACRAE & CO.

(54) Titre : COMPOSITIONS DE LIANT D'ASPHALTE A MELANGE CHAUD CONTENANT DES ADDITIFS LUBRIFIANTS
(54) Title: WARM MIX ASPHALT BINDER COMPOSITIONS CONTAINING LUBRICATING ADDITIVES



(57) Abrégé/Abstract:

(57) *Abzige/Abstract.* A functionally dry warm mix asphalt binder composition modified with lubricating additives that can be mixed with aggregate and compacted at temperatures substantially below asphalt binder compositions that do not contain the disclosed lubricating additives.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
12 March 2009 (12.03.2009)

PCT

(10) International Publication Number
WO 2009/033060 A1(51) International Patent Classification:
C08L 95/00 (2006.01) *E01C 7/00* (2006.01)(74) Agents: **BUSSE, Paul, W.** et al.; 90 South 7th Street, 2200 Wells Fargo Center, Minneapolis, MN 55402 (US).(21) International Application Number:
PCT/US2008/075452

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date:
5 September 2008 (05.09.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/970,809 7 September 2007 (07.09.2007) US
60/976,141 28 September 2007 (28.09.2007) US
11/871,782 12 October 2007 (12.10.2007) US

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

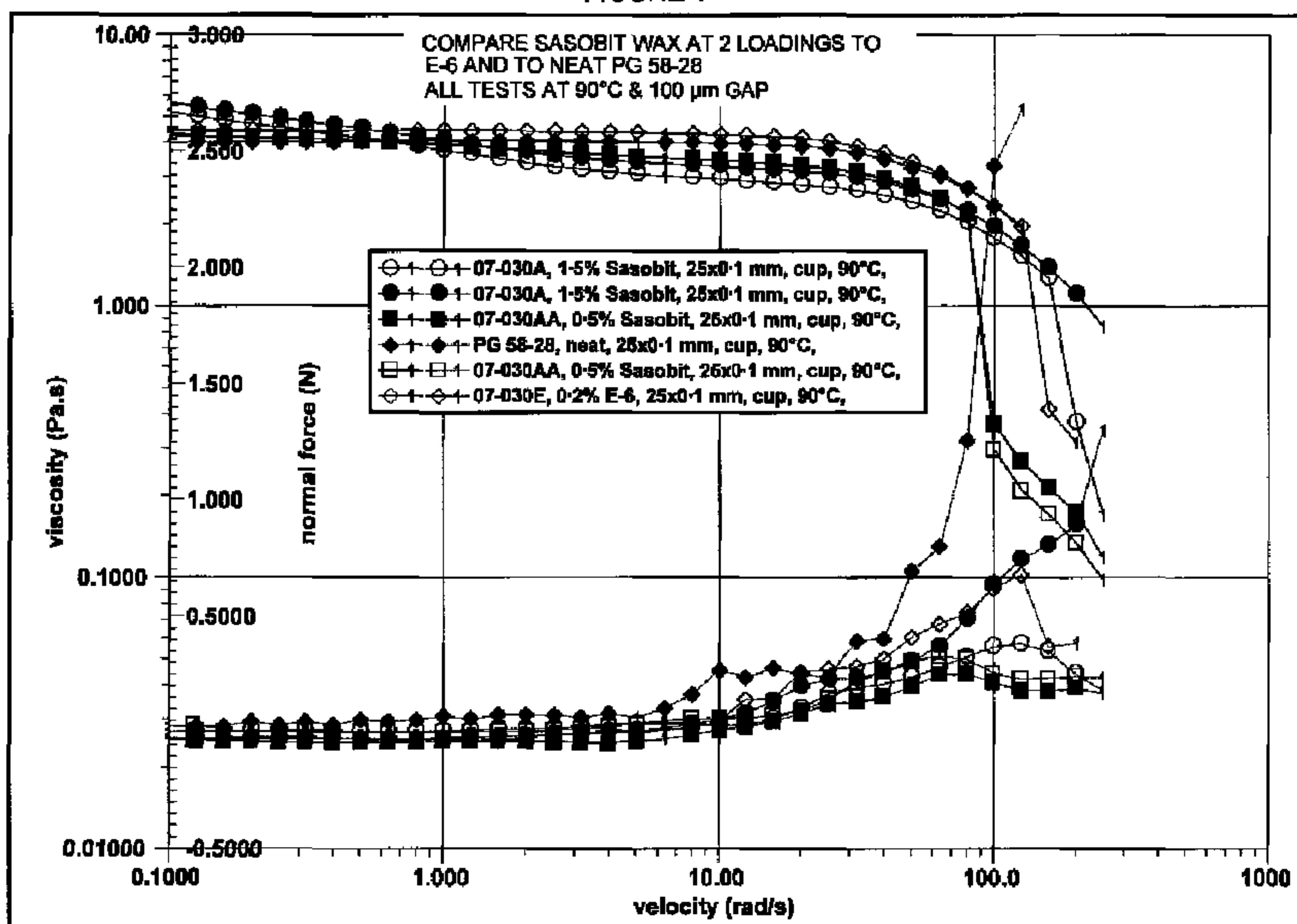
(71) Applicant (for all designated States except US): **ALM HOLDING CO.** [US/US]; 920 - 10th Avenue North, Onalaska, WI 54650 (US).

Published:

- with international search report
- before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments

(54) Title: WARM MIX ASPHALT BINDER COMPOSITIONS CONTAINING LUBRICATING ADDITIVES

FIGURE 1



WO 2009/033060 A1

(57) Abstract: A functionally dry warm mix asphalt binder composition modified with lubricating additives that can be mixed with aggregate and compacted at temperatures substantially below asphalt binder compositions that do not contain the disclosed lubricating additives.

**WARM MIX ASPHALT BINDER COMPOSITIONS CONTAINING
LUBRICATING ADDITIVES**

BACKGROUND

5 International Application WO 2007/032915, and United States Published Application 2007/0191514, report a warm mix asphalt binder composition and process that injects a foaming, lubricating solution into a stream of asphalt cement prior to incorporation of the asphalt cement plus foaming, lubricating solution with aggregate at reduced temperatures to produce a warm mix asphalt paving mixture.

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SUMMARY

The present invention provides functionally dry warm mix asphalt binder compositions, polymer modified asphalt binder compositions or polymer/acid-modified asphalt binder compositions that have been modified with a lubricating additive such as lubricating non-aqueous surfactants, lubricating non-surfactants, lubricating acids or combinations thereof. The term "functionally dry" as used herein in connection with compositions, aggregates or mixtures is used to describe reduced water content compositions, aggregates or mixtures, particularly those in the "warm mix" regime, as further described herein. The mentioned lubricating non-aqueous surfactants, non-surfactants or acids, such as polyphosphoric acid additives, provide asphalt binder compositions that may be adequately mixed with aggregate at temperatures 30-50°F lower, even more than 50°F lower, or as much as 100°F lower than a substantially similar asphalt binder or cement that does not contain these lubricating additives or combinations thereof. In addition, these asphalt-aggregate mixtures may be compacted at temperatures 30-50°F lower, even temperatures more than 50°F lower, or as much as 100°F lower than a substantially similar asphalt-aggregate mixture that does not contain a lubricating additive or combinations thereof. Another meaning for the term "functionally dry" as used herein is "essentially water-free" as described below.

The term "lubricating additive" includes materials described below that may be added to asphalt binders to provide compositions that have a normal force at warm mix temperatures of less than 2 newtons at a gap width of 50 microns when the normal force is measured according to the laboratory testing for lubricity procedures set out below. In

some embodiments, the normal force at warm mix temperature is less than 1 newton or, in other embodiments may be less than 0.5 newtons. Warm mix temperatures may vary according to the grade of asphalt binder that is used. For example, warm mix temperatures for a PG 58-28 asphalt binder containing a lubricating additive are less than 130°C. In another example, warm mix temperatures for a PG 70-28 asphalt binder containing a lubricating additive are less than 150°C.

The asphalt binder compositions and aggregate mixtures that contain lubricating additives disclosed in the present application may also include liquid antistripping additives used in conventional asphalt-aggregate mixtures.

Methods of preparing the present asphalt binder compositions as well as methods of using the present asphalt binder compositions mixed with aggregate to prepare paved surfaces are also disclosed in this application.

A first embodiment of the present invention is a warm mix, functionally dry asphalt binder composition comprising a lubricating surfactant. Suitable lubricating surfactants include neutral, cationic and anionic surfactants. One suitable surfactant is an ethoxylated tallow diamine surfactant. In alternative embodiments of the invention, the lubricating surfactant can be used in an amount of about 0.1-1.0 wt% of the asphalt binder composition.

A second embodiment of the present invention is a functionally dry warm mix asphalt binder composition comprising a lubricating non-surfactant wax. Suitable lubricating non-surfactants include waxes such as montan waxes, petroleum waxes or amide waxes. In alternative embodiments of the invention, the lubricating wax may be used in amount of about less than 2.5 wt% of the asphalt binder composition. In other alternative embodiments of the invention the wax may be used in an amount of about 0.1-0.5 wt%.

A third embodiment of the present invention is a functionally dry warm mix asphalt binder composition comprising a lubricating acid such as, for example, anhydrous phosphoric acid. Suitable lubricating phosphoric acid grades include polyphosphoric acid (PPA), superphosphoric acid (SPA), or other grades of phosphoric acid. One suitable phosphoric acid derivative is polyphosphoric acid (commercially available from ICL, St. Louis, MO). In alternative embodiments of the invention, the

lubricating phosphoric acid derivative may be used in an amount of about 0.2-1.0 wt% of the asphalt binder composition.

Each of these and other embodiments of the present asphalt binder compositions may be mixed with aggregate at a temperature of about 280°F and lower temperatures (where this mixing temperature may be a function of the original or starting PG asphalt grade, viscosity or penetration of the binder) and the resultant mixture may be compacted at a temperature of about 260°F and lower temperatures (where this compaction temperature may also be a function of the original or starting PG asphalt grade, viscosity or penetration of the binder). Hot mix asphalt mixtures produced from the same binders not utilizing the present invention are reasonably expected to require respective mixing and compaction temperatures 70-100°F higher than those temperatures stated above.

Another embodiment of the present invention is a functionally dry warm mix polymer/acid modified asphalt binder composition comprising a lubricating surfactant, a lubricating wax or both.

Still another embodiment of the present invention is a functionally dry warm mix polymer modified asphalt binder composition comprising a lubricating surfactant, or a lubricating non-surfactant or both. This embodiment provides a modified asphalt binder composition that can be mixed with aggregate at a temperature that is at least 30-50°F below, even temperatures more than 50°F lower, or as much as 100°F lower than the temperature that is adequate to mix a similar modified asphalt binder composition that does not contain a lubricating surfactant, a lubricating wax or a lubricating acid or combinations thereof.

In another embodiment, the lubricating additives described in the present application allow using a stiffer binder in a paving application while retaining the desired physical properties of a binder that is less stiff.

In another embodiment, the lubricating additives described in the present application allow using recycled asphalt pavement (RAP) or increased amounts of RAP in a paving application while retaining the desired physical properties of the paving.

The use of stiffer binders may allow the use of more readily available or more economical grades of an asphalt binder. For example, the use of these lubricating additives may allow substituting a PG 58-22 asphalt binder for a PG 58-28 binder

without sacrificing the low temperature cracking properties provided by the less stiff PG 58-28 binder. Similarly, the lubricating additives may allow using a PG 64-16 asphalt binder as a substitute for a PG 64-22 asphalt binder.

The present invention also includes forming a paved surface using the novel
5 warm mix composition described herein. In this aspect, a paving mix may be made in the temperature ranges described herein using the composition described. The mixing typically occurs away from the paving site (both in-line injection and preblended mixing processes, as well as other mixing processes, are included), and the mixture is then hauled to the site and supplied to a paving machine. The mixture of the lubricated
10 asphalt binder composition and aggregate is then applied by the paving machine to a prepared surface after which it is usually roller compacted by additional equipment while still at an elevated temperature. The compacted aggregate and asphalt mixture eventually hardens upon cooling. Because of the large mass of material in paving a roadway or commercial parking lot, the cost of the thermal energy to achieve suitable
15 mixing and paving is reduced because of the reduction in the temperature necessary in the mixture for proper paving. This will result in cost savings attributable to the present invention because of the reduced need for thermal energy to be supplied or maintained in the mixture. For common binders used in the practice of the present invention, the visco-lubricity characteristics of the binder and lubricating additive composition affect
20 the temperature needed to provide thorough coating of the aggregate and application and compaction of the asphalt-aggregate mixture according to the present invention.

Accordingly, in one aspect, the present invention includes a paved surface formed using the novel warm mix composition described herein. Such a paved surface comprises a compacted mixture of an aggregate and a functionally dry warm mix
25 asphalt binder composition including an asphalt binder, and a lubricating additive such as a lubricating surfactant, a lubricating non-surfactant additive, a lubricating acid or combinations thereof. In another aspect, the present invention includes a method of forming a paved surface using the novel warm mix composition described herein.

The present inventive process includes adding a lubricating substance into an
30 asphalt binder heated to within a warm mix temperature range to create a warm mix lubricated asphalt binder composition; combining the warm mix lubricated asphalt binder composition with a suitable aggregate; mixing to coat the aggregate with the

lubricated asphalt binder composition to form a warm mix paving material; transferring the warm mix paving material to a paving machine; applying the warm mix paving material with the paving machine at a warm mix paving temperature to a prepared surface; and then compacting the applied paving material to form a paved surface.

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BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a graph plotting measured viscosity and normal force properties with respect to velocity as a measure of lubricity of an asphalt cement and an asphalt cement modified with a lubricating surfactant.

10 Fig. 2 is a graph plotting measured viscosity and normal force properties with respect to velocity as a measure of lubricity of an asphalt cement and two asphalt cements modified with a lubricating wax.

Fig. 3 is a graph plotting the measured viscosities and normal forces with respect to velocity as a measure of lubricity of an asphalt cement at three different temperatures.

15 Fig. 4 is a graph plotting the measured viscosity and normal force properties with respect to velocity as a measure of lubricity of an asphalt cement, a related polymer-acid modified asphalt cement further modified with polyphosphoric acid, a polymer-acid modified asphalt cement further modified with a liquid antistripping additive and a polymer-acid modified asphalt cement further modified with a lubricating surfactant.

20

DETAILED DESCRIPTION

We have found that field-produced warm mixes using a foaming, lubricating solution may be adequately compacted at temperatures approximately 30-50°F or more below typical hot mix asphalt compaction temperatures days after field production.

Testing of mix samples taken at the paver have shown that this mix contains approximately 0.5 wt%, or less, water which is an amount of water well below the amount of water generally utilized in conventional warm mix production. The only component of the foaming, lubricating solution remaining with the asphalt mixture is an effective concentration of the surfactant providing the lubricating effect. This observation indicates that the incorporation of water in conjunction with a foam for the production of warm mix is not an essential component in all instances, although the water may be used in a system for delivery of the lubricating additive into the asphalt binder or cement. The present invention thus relies, in part, in determining that the

lubricating properties of additives added to an asphalt binder or cement are an important component of the present warm mix asphalt mixtures and that it is not necessary or essential to use foamed asphalt binders or emulsified asphalt binders that are used in warm mix asphalt binder compositions, mixtures and paving processes.

5 As used in the present application, each of the terms “functionally dry” or “essentially water-free” means or is intended to refer to an asphalt binder composition that contains less water or moisture than is routinely used in conventional or known warm mixes. This term does not mean and is not intended to refer to a warm mix composition that is completely free of water, moisture or added water. For example, 10 aggregate that will be mixed with the present asphalt binder compositions will also contain varying amounts of water and that water may affect the aggregate coating process. In embodiments of the present invention it is acceptable that there is some moisture contained in the aggregate, because a completely dry aggregate is not practical or may not be desirable. The amounts of water or moisture in the aggregate will vary for 15 any number of reasons including but not limited to the particular geographical region where the aggregate is crushed or stockpiled, the local weather conditions, the local temperature or the particular stockpile facilities. Due to this variation in the water content of the aggregate, there may be adjustments made to the actual water content of the asphalt binder compositions of this invention before the aggregate is coated with the 20 asphalt mixture in order to achieve acceptable coating of the aggregate. If the aggregate is either very wet or very dry, the water content of the aggregate may be adjusted or altered. Alternatively, or in addition, the water or moisture content of the asphalt binder composition may be adjusted or altered in order to optimize or ensure adequate coating of the aggregate during mixing. Warm mixes of the present invention will generally 25 include about 2-9 wt% asphalt binder composition and about 91-98 wt% aggregate. In other embodiments, the warm mixes will include about 3-8 wt% asphalt binder composition and about 92-97 wt% aggregate. The amount of asphalt binder composition required will depend upon mix type, layer in the pavement structure, aggregate size, traffic considerations, or other factors.

30 The moisture content of the asphalt binder composition may be changed in a number of ways such as injecting or spraying water into the asphalt binder compositions. Even though the asphalt binder compositions may have the water or

moisture content adjusted or altered, these compositions are considered to be functionally dry when the overall water content is lower or substantially lower than other known or conventional warm mix asphalt binder compositions and mixtures.

In addition, different grades of asphalt will have different mixing properties and 5 conditions. Adjustments or alterations of the water or moisture concentrations that take into account different asphalt grades may provide functionally dry (or essentially water-free) asphalt binder compositions. When variations in the water contents of different aggregates and different asphalt grades are accounted for, the asphalt-aggregate mixes or mixtures of the present invention will typically have a water content of less than about 5 10 wt%. In many instances the water content is less than about 4 wt%, less than about 3 wt%, less than about 2 wt% or less than about 1 wt%. In certain embodiments of this invention, the asphalt binder compositions comprise less than about 0.5 wt% water. It is understood, however, that water contents outside this range may still be within the scope 15 of the present claims and embodiments of the invention when the claimed compositions contain the lubricating additives, including the non-aqueous surfactants, lubricating non-surfactants and acids, disclosed in this application.

Surfactants (in both aqueous or non-aqueous form) are a class of lubricating additives that may, when incorporated into an asphalt binder or cement at levels as low 20 as 0.1 wt%, provide sufficient lubrication of the asphalt cement so that aggregate may be adequately coated at temperatures 30-50°F lower, even more than 50°F lower, or as much as 100°F lower than the temperatures normally needed to produce a bituminous mixture without an added lubricating additive. The lubricating additive then enables compaction of these mixtures at 30-50°F lower, even more than 50°F lower, or as much 25 as 100°F lower than the temperatures normally needed for compaction of otherwise similar bituminous mixtures.

Non-aqueous surfactants as additives have been incorporated into hot mix asphalt cement to provide improved moisture resistance, however, their value and function as a lubricating additive in warm mix asphalt and specifically as a functionally dry or water free warm mix composition have not been recognized by those skilled in the art prior to 30 the disclosure of the elements and examples of this invention. Suitable lubricating surfactants as additives include naturally occurring compounds and more commonly synthesized chemical compounds from three categories of surfactants: detergents,

wetting agents and emulsifiers. Surfactant additives may be specifically grouped into four classifications: i) anionic surface agents to include, but not limited to, fatty acids (saturated and unsaturated fatty acids), fatty acid pitch (stearic acid pitch), fatty acid derivatives (fatty acid esters and fatty acid sulfonates), and organo phosphates (alkyl phosphates); ii) cationic surface agents to include, but not limited to, alkyl amines, alkyl quaternary ammonium salts, heterocyclic quaternary ammonium salts, amido amines, and non-nitrogenous sulfur or phosphorous derivatives; iii) ampholytic surface agents to include, but not limited to, amino acids, amino acid derivatives, betain derivatives (alkylbetrains and alkylaminobetrains), imidazolines, and imidazoline derivatives; and iv) non-ionic surface agents to include, but not limited to, fatty acids with ester bonds (SPANS and TWEENS), surfactants with ether bonds (alkylphenolpolyoxeythylenes and polyoxyethylenated alcohols), surfactants with amid bonds (alcanolamides, mono and diethanolamides and their derivatives), alkylated oxide copolymers and polyoxyethylenated mercaptans.

Lubricating non-surfactants based on wax chemistry have been incorporated into an asphalt binder or cement to produce warm mix based on the concept that these wax additives reduce the viscosity of the wax asphalt blend to an extent sufficient to enable production and lay down of the asphalt-aggregate mixture at reduced temperatures, when incorporated into an asphalt binder or cement at levels as low as 0.1 wt%, provide sufficient lubrication of the asphalt cement so that aggregate may be adequately coated at temperatures 30-50°F lower, even more than 50°F lower, or as much as 100°F lower than the temperatures normally needed to produce a bituminous mixture without an added lubricating additive. The lubricating additive then enables compaction of these mixtures at 30-50°F lower, even more than 50°F lower, or as much as 100°F lower than the temperatures normally needed for compaction of otherwise similar bituminous mixtures.

The data in this application indicates that wax additives in an amount less than about 2.5 wt%, such as Sasobit™ wax (Sasol North America Inc.) and montan wax (Romanta, Amsdorf, Germany or Strohmeyer and Arpe, NJ), when used for this application have only a minor effect on reducing the viscosity of the asphalt-wax blend, but such additives, even at usage levels well below those generally employed, provide a noticeable and beneficial lubricating effect on the asphalt-wax combination. Exemplary

usage levels may include less than about 2 wt%, less than about 1.5 wt%, less than about 1 wt%, or less than about 0.5 wt %. Lubricating non-surfactants based on wax chemistry may be selected from paraffin and non-paraffin waxes. Paraffin waxes include, but are not limited to, petroleum derived and refined waxes (slack wax and refined micro-crystalline wax) while non-paraffin waxes include, but are not limited to, natural waxes (animal and vegetable waxes e.g. bees wax and carnauba wax), modified natural waxes (brown coal derivatives, e.g., montan wax and mineral oil derivatives), partial synthetic waxes (acid waxes, ester waxes, amid waxes, alcohol waxes and oxidized polyethylene waxes), or full synthetic waxes (Fischer-Tropsch waxes and polyethylene waxes).

Other lubricating non-surfactants such as viscosity modifiers (VMS), dispersant viscosity modifiers (DVMS), and additives containing viscosity modifiers or dispersant viscosity modifiers as well as extrusion and molding production processing aids, polyolefins and sulfur, may provide lubricating characteristics to petroleum products and may also be used as a non-surfactant additive for functionally dry or waterless warm mix asphalt formulations. Such additives include, but are not limited to, VMS and DVMS used in engine lubricating oils (polyisobutylenes, olefin copolymers, hydrogenated styrene-diene copolymers, styrene maleate copolymers, polymethacrylates, olefin-graft PMA polymers and hydrogenated polyisoprene star polymers) and products containing VMS and DVMS such as the residual bottoms from refined recycled engine lubricating oils; processing aids used in extrusion and molding operations (high trans content polyoctenamer reactive polymer), polyolefins (ethylene vinyl acetate (EVA), acrylic polymers and silicones); sulfur or sulfur compounds (sulfur impurities in fuels may provide lubrication properties). Exemplary usage levels may include less than about 2 wt%, less than about 1.5 wt%, less than about 1 wt%, or less than about 0.5 wt %.

Different concentrations of polyphosphoric acid, are another class of additives that can, when incorporated into an asphalt cement at levels as low as about 0.2-1.0 wt%, provide sufficient lubrication of the asphalt cement so that aggregate may be adequately coated at temperatures 30-50°F, or greater difference, below the temperatures normally needed to produce a bituminous mixture without the polyphosphoric acid additives.

5 The data set out in the examples indicate that the addition of surfactant in non-aqueous form enables utilization of asphalt cements that have been produced using acid modifiers. For example, acid modifiers from the type of polyphosphoric acid (PPA) or superphosphoric acid (SPA), although other grades of phosphoric acid and other types of acids, such as mineral acids, other inorganic acids or organic acids, may be utilized with the present invention.

10 While not intending to be bound by theory, the present invention is based, in part, on the observations that lubricating additives may be used without added water to provide a warm mix having desired visco-lubricity characteristics or properties. As used in this application the term “visco-lubricity” means a characteristic of a material exhibited under high rotational velocity as the gap thickness of the material being tested approaches zero. As the gap thickness is reduced and as rotational velocity is increased, the material’s viscosity begins to decrease but the normal force between the plates begins to increase. A material that has good visco-lubricity characteristics will exhibit 15 less normal force increase than one which has poor visco-lubricity. Stated another way, the ability of the material being tested to enable the plates to easily rotate relative to each other becomes more important than the viscosity of the material being tested. An example illustrating the meaning of the term “visco-lubricity” is the observed reduced requirements for hot mixing and compaction temperatures of polymer modified asphalt 20 binders compared to conventional asphalt binders. Based solely on viscosity data, polymer modified binders should require mixing and compaction temperatures that are 20-50°F higher than those which common practice have found to be adequate. We believe that these polymer systems could have visco-lubricity properties that provide adequate mixing to coat aggregate particles and further provide mix compaction at 25 temperatures substantially below those predicted based on viscosity alone.

Another example illustrating the meaning of the term visco-lubricity is the reduction in dry tensile strength of many mixtures produced using conventional asphalt binders combined with liquid antistrip or antistripping additives. Those skilled in the art 30 of performing tensile strength ratio (TSR) tests to verify that bituminous mixtures will not be water sensitive, have seen that the dry tensile strength of mixtures using antistrip treated binders can be noticeably lower than the dry tensile strength of the same mix produced with the same binder but without antistrip. This observation has typically been

attributed to a reduction in binder viscosity or stiffness due to the addition of the antistrip to the binder. However, there may be minor reduction in viscosity or stiffness when low levels of antistrip are added to the binder. We believe that this tensile strength reduction is an example of the antistrip lubricating the mix resulting in the 5 observed reduced dry tensile strength. A typical recent example will serve to make the point.

A PG 58-28 with and without a polyamine antistrip was used to produce a hot mix asphalt composition for tensile strength ratio testing according AASHTO test method T-283. Rheological properties of the PG 58-28 with and without the antistrip 10 were determined. All results are shown in Table 1. For these particular samples there is actually a slight increase in stiffness after the addition of the antistrip (6.3% increase) and yet the dry tensile strength of the mix with the antistrip is reduced by 22.7% based on the average values of the two results using the PG 58-28 without antistrip. The wet 15 strength is reduced by only 8.4%. This reduction in dry tensile strength, which does not occur with all mixes and all binders, may be observed in some mixes and binders. Based on the present warm mix work and lubricity testing disclosed herein, the dry tensile strengths are being reduced due to the lubricating effect of antistripping additive. The specimens tested for wet strength are typically saturated to a level of 60 to 80%. The reduced strength of saturated mixes without antistrip is typically attributed to 20 debonding of the binder from the aggregate, which typically can be visually verified. When an antistrip functions as desired there is little or no visual debonding of binder from the aggregate, but the comparative reduction in wet strength of the antistrip treated mix is related to the lower dry strength value due to the lubricating effect of the antistrip.

25

Table 1

Sample	% AC	DSR, G*/sin(δ) @ 58°C, kPa	Complex viscosity @ 58°C, Pa·s	Dry Strength, PSI	Wet Strength, PSI	TSR
58-28, no antistrip	5.5%	1.33	133	78.2	51.9	66.4%
58-28, no antistrip	5.8%	1.33	133	72.4	47.7	65.9%
58-28, 0.3% polyamine antistrip	5.6%	1.42	142	58.2	45.6	78.4%

Laboratory Testing of Lubricity

Since there are no readily available rheological tests identified for determining the lubricity of asphalt cement, the following test provides comparative testing of asphalt cement at different temperatures and with different additives to determine lubricity. This test is described as follows.

1. An AR2000 dynamic shear rheometer using a heated air test chamber was utilized.

2. A shallow cylindrical cup measuring approximately 35 mm in diameter and approximately 5 mm in height was used to contain the liquid being tested. This cup was secured to the bottom pedestal of the test fixture in the rheometer.

3. A small quantity of the asphalt cement or asphalt cement plus lubricating additive was added to the bottom of the cup. A 25 mm diameter flat plate was used as an upper test fixture in the rheometer. This upper test fixture is a typical test fixture used in plate-plate rheological testing with this instrument.

4. The plate attached to the upper test fixture is brought into contact with the specimen in the cup and the gap is reduced until a membrane of material to be tested is either 100 or 50 μm thick.

5. The test used is a steady shear test with increasing velocity. The specimen is maintained at a constant temperature while the upper plate rotates in one direction with a programmed increase in angular velocity. As the rotational speed increases the drag between the upper plate and the bottom of the cup increases. In addition, normal force increases, attempting to force the plates apart. The more lubricating character an additive has the lower the normal force buildup.

In reference to Figures, the upper sets of plotted data are for viscosity, while the lower sets of plotted data are for normal force.

Example 1 and Data Represented in Figure 1

A neat PG 58-28 asphalt cement was tested as described above at 90°C (194°F) as being representative of a low end, but not uncommon, warm mix asphalt compaction temperature. A material thickness of 100 μm was used. Figure 1 illustrates that, as the test velocity increases, the viscosity of the material is nearly steady and then begins to gradually decrease until a point is reached where the viscosity decreases very rapidly.

For the neat PG 58-28 (black solid diamonds) the normal force begins to increase at a velocity of approximately 50 radians/sec. As the test velocity increases the normal force increases for the neat asphalt until the endpoint of the test is reached. The normal force increases to approximately 2.7 newtons. Several different additives and usage levels are 5 compared in this plot. Two different tests of the PG 58-28 with 1.5 wt% Sasobit™ wax are shown, the open and solid circles. In one test (the open circle) the normal force reached a value of approximately 1.2 newtons before the test terminated. In the other test (solid circles) the normal force reached about 0.4 newtons. Two tests at a usage 10 level of 0.5 wt% Sasobit™ wax are also shown (open and solid squares). In both of those tests the maximum normal force never exceeded 0.4 newtons. Lastly, E-6, an ethoxylated tallow diamine (Akzo Nobel Co.), was added at 0.2% by weight to the PG 58-28 and tested (open diamond). This sample achieved a maximum normal force of approximately 0.7 newtons before decreasing. For all blends it is possible to observe 15 that the viscosity of the neat asphalt and the asphalt plus additives is similar from blend to blend for low to medium velocities. The normal forces are also similar until the test velocity becomes quite high. Then the blends with the additives exhibit lower normal forces and in several instances the normal force values peak and then diminish. The data in this plot supports the assertion that (1) the addition of wax additives such as Sasobit™ wax do not appreciably diminish the viscosity in the low to medium velocity 20 ranges of the asphalt cement at warm mix compaction temperatures (regardless of dosage level) and (2) the addition of the wax additive does provide evidence of lubricating the blend compared to the control, neat PG 58-28.

Example 2 and Data Represented in Figure 2

25 To better differentiate between neat asphalt and asphalt containing lubricating additives, the gap in the testing fixture was reduced to 50 μm . Figure 2 illustrates the normal force comparison of neat PG 58-28 (open circles), 1.5 wt% Sasobit™ wax (open squares), 1% montan wax (solid squares) and 0.5 wt% Sasobit™ wax (solid circles). The normal force for the neat PG 58-28 increases to approximately 8 newtons at 100 30 radians/second. The normal force for the 1.5 wt% Sasobit™ wax increases to approximately 5.5 newtons before decreasing. Both the 1 wt% montan wax and 0.5 wt% Sasobit™ wax only reach a normal force maximum of about 3 newtons. For all of these

blends note that the viscosities of the various samples are very nearly identical in the low and medium velocity ranges, indicating that the wax additives are not functioning by a mechanism of decreasing the viscosity of the asphalt and wax blends.

5 Example 3 and Data Represented in Figure 3

A common way to achieve properties suitable for an asphalt cement that enable it to be compacted is to increase its temperature. Figure 3 illustrates the variation in viscosity and normal force for a neat PG 58-28 at 3 different temperatures; those temperatures being 90°C (194°F), 100°C (212°F) and 125°C (257°F). Figure 3 illustrates that as the temperature increases the viscosity decreases, as would be expected. Figure 3 also illustrates that between a test velocity of 10 and 20 radians/second the normal force begins to increase. As the test temperature increases the normal force peak shifts to lower values at ever increasing velocity values. At 100 radians/second the 90°C sample exhibits a normal force of about 9 newtons, the 100°C sample exhibits a normal force of about 4.5 newtons and the 125°C sample exhibits a normal force of just under 2 newtons. It is instructive to realize that typical hot mix asphalt materials are initially compacted in the range of 125°C but are not initially compacted at 90°C. This data indicates that warming neat PG 58-28 provides lubricating properties in the binder that are acceptable for compaction, whereas typically contractors would not allow a paving mix to cool to a temperature as low as 90°C before beginning compaction. Therefore hot mix and warm mix are on a continuum line of temperature and it is the nature of the additives that enable warm mix materials to be compacted adequately at temperatures in the 90-100°C range.

25 Example 4 and Data Represented in Figure 4

Example 4 illustrates the impact of polyphosphoric acid (PPA) plus other additives on the reduction of normal force buildup in the asphalt binder. A polymer modified PG 58-34 which also contains PPA as a reactant was tested in duplicate (open and solid circles). Additionally, 0.5 wt% INNOVALT W phosphate ester antistripping material was added to the PG 58-34 and tested and in another sample 0.3 wt% E-6 ethoxylated tallow diamine was added to the PG 58-34. All of these samples were compared to a standard PG 58-28. All tests were conducted at 90°C with a 50 µm test

gap. The data plotted in Figure 4 indicate that even though the viscosities of the 58-34 and its blends (upper curves on the plot) are greater than the viscosity of the PG 58-28, the normal force values are uniformly lower at 10 radians/second and higher. The INNOVALT W added to the PG 58-34 showed the greatest reduction in normal force build-up, but the PG 58-34 with just the acid additive also showed surprising reduction in normal force relative to a neat, unmodified binder. In summary, PPA at typical usage levels (0.2 to 1 wt%) can serve as a lubricating additive in the production of warm mix asphalt binder compositions.

10 Example 5

A PG 64-28 asphalt binder was made by blending 0.75 weight percent polyphosphoric acid with a PG 58-28 asphalt cement. To this blend was added 0.5 wt% phosphate ester antistripping additive and 0.2 wt% of E-6 ethoxylated tallow diamine. This asphalt binder blend was mixed using no water at 230°F with a gravel aggregate. A 15 100% coating was achieved of the aggregate at this temperature. The mix was compacted to produce Hamburg rut testing specimens at 230°F achieving the density values expected of a hot mix asphalt.

One test of a paved material's performance is to simulate vehicle traffic stress by the number of repetitive passes a roller supporting a specified weight load must make to cause formation of a rut of a specified depth in the material. Such testing of compacted material produced by the inventive process was done using a testing machine referred to as a Hamburg Wheel Tracking Tester ("HWT"), also known as a PMW Wheel Tracker, available from Precision Machine and Welding, Salina, Kans. The number of Hamburg passes required to reach a rut depth of 10 mm when the compacted material tested in a 20 dry condition was used for comparative evaluation. The test conditions were 158 lb. wheel load, 52 passes per minute at the test temperature using heated air to achieve the specimen test temperature. Generally, when all other variables are essentially the same, the greater the number of passes, the better the anticipated paving mix performance. 25 Those persons of ordinary skill in the art and familiar with the HWT will recognize paving materials that are suitable for a particular application based on the results that are 30 provided when samples are subjected to these test conditions.

Rut tests were performed on specimens produced as identified above using completely dry aggregate and compared to rut tests performed on specimens produced using the same 64-28 plus 0.5 weight percent phosphate ester plus 0.2 weight percent of E-6 introduced using a water dispersed solution (as set out in United States Published Application 2007/0191514). Hamburg rut tests were conducted at 50°C in a water immersed procedure. The average number of rut passes to reach 12.5 mm of rutting was 7300 for the specimens prepared according the procedure of this invention and 4176 according to the procedure using the aqueous, foaming lubricating solution. Further the binders from specimens from each rut test were extracted and recovered and the rheological properties determined at 64°C. The PG 64-28 plus 0.5 weight percent phosphate ester antistrip had a test value for $G^*/\sin(\delta)$ of 1.12 kiloPascals at 64°C. The binder recovered from the mixture produced using the foaming, lubricating solution had a test value of 1.27 kiloPascals and the binder recovered from the mixture produced using the procedure of this invention had a test value of 1.99 kiloPascals. Normally one would expect the value of $G^*/\sin(\delta)$ to increase as a result of mixing and recovery. While there was a slight increase using the foaming lubricating solution it is most likely that a more substantial increase was counteracted by the interaction of the polyphosphoric acid with the water from the foaming solution and the basic character of the dispersed E-6 diamine. By adding the E-6 in non-aqueous form as per this invention the value of $G^*/\sin(\delta)$ increased to greater and more typical extent while still maintaining the ability of the mixture to be produced and compacted under warm mix conditions. The above further supports the embodiment of the present invention for the production of warm mix using binders containing acid modifiers.

25 Example 6

A field trial using 300 tons of mix that was produced from PG 58-28 asphalt binder with 0.3 wt% polyamine antistripping additive and 0.3 wt% E-6 ethoxylated tallow diamine added. This mix was made at a counterflow drum mix plant and placed on a private road. The mix contained 20% RAP and warm mix was produced at a temperature of about 220-240°F. Compaction took place at temperatures ranging from 205- 220°F. Typical hot mix temperatures for this same mix were 310°F mix temperature and initial compaction temperatures in the range of 285°F and higher. Field

cores obtained one day after mix laydown and compaction showed results of 93.3% and 93.8% of maximum theoretical density. The target density for this mix by specification is 92.0% or greater.

5 **Example 7**

A field trial consisting of 700 tons was conducted using a PG 58-28 binder with 0.3 wt% polyamine antistripping additive and 0.3 wt% E-6 ethoxylated tallow diamine added. This blend was mixed with a limestone aggregate through a counterflow drum mixing facility. Warm mix was produced at temperatures varying from 210°F to as high 10 as 260°F due to plant variations caused by low production rates during the trial. However, when the mix discharge temperature was stabilized at 225 - 235°F the coating of the aggregate was at 100%. This mixture was further taken to an on-going road project and successfully paved at temperatures ranging from 225°F to as low as 200°F. Cores cut from this trial pavement exhibited in place densities of 90.8%, 91.6%, 92.2%, 15 91.2%, 92.1% and 94.0% with values of 91-92% being typical for in place densities when this type of mix is placed as a hot mix. The mixture produced during this trial contained 20 wt% reclaimed asphalt pavement (RAP). This is significant because the utilization of RAP is an important component of the Hot Mix Asphalt (HMA) paving industry. Although the top end amount of RAP in warm mix is a matter of choice, an 20 amount could be greater than about 50 wt% because of the requirement that the warm mix discharge temperature be kept low relative to conventional HMA. This same mixture when produced as a conventional hot mix asphalt was mixed at a temperature of 300-310°F and compacted at temperatures approximately 15-20°F cooler than the mix temperature.

25

Example 8

A field trial was conducted using a PG 58-28 binder with 0.3 wt% polyamine antistripping additive and 0.3 wt% E-6 ethoxylated tallow diamine added. This blend was then mixed with aggregate containing 30 wt% RAP at mixing temperatures ranging 30 from 220-240°F. Compaction took place at temperatures ranging from 205-225°F. After this asphalt binder composition was mixed with aggregate, applied and compacted the pavement densities were determined using standard industry procedures.

The following densities were measured.

1 foot off center line - 95.4% of maximum theoretical density

6 feet off center line - 94.7% of maximum theoretical density

Shoulder of road paved over crushed aggregate base - 92.5% of maximum

5 theoretical density

The two pavement densities were taken on pavement sections paved over conventional hot mix asphalt. Typically the first layer of mix paved over aggregate has lower density because the underlying structure is not as rigid. Target mix density for the mix over pavement is 92% or higher and the density for shoulder mix over crushed aggregate is 91% or higher. This warm mix sample had measured physical properties that were above minimum properties for conventional heat mix samples.

Example 9

A treated asphalt binder composition of PG 58-28 binder modified with E-6 ethoxylated tallow diamine surfactant and polyamine antistripping additive was added to a tank that had held an untreated asphalt. As a mix with aggregate containing 30 wt% RAP was beginning to be made, the untreated binder in the tank was first pumped into a mixing drum at warm mix temperatures. This untreated binder did not produce a coated asphalt-aggregate mix. After some time when the treated binder was being eventually incorporated into the mix, good coating in the 220 – 240°F temperature range was achieved. Approximately 700 tons of this warm mix was placed and compacted in the field at temperatures ranging from about 212 – 228°F. A sample of this mix was taken for moisture content determination just as the mix was discharged from the mixing drum at a discharge temperature of about 235°F. The sample was placed in a plastic container and sealed. Within 30 minutes this sample was tested for moisture content using a solvent refluxing procedure, ASTM D 1461. The moisture content of the mix was 0.25 wt%.

After this asphalt binder composition was mixed with aggregate, applied and compacted, the pavement densities were determined using standard industry procedures.

30 The following densities were measured from randomly selected samples – 93.3%, 93.4% and 93.8% of maximum theoretical density. Normal hot mix produced at this plant with the same aggregate and RAP materials and untreated PG58-28 was mixed at

325°F and paved at approximately 300°F and compacted 5-10°F below the paving temperature.

Example 10

5 Using the same aggregate and RAP as Example 9, about 200 tons of warm mix was prepared using a blend of PG 58-28 binder, 0.5 wt% Sasobit wax and 0.3 wt% polyamine antistripping additive. A well coated warm mix containing 30 wt% RAP was produced at temperatures ranging from 215- 240°F. When the mix was produced on the cooler end of this temperature range, there was tendency of the mix to drag due to
10 sticking on the paver screed. However, when the mixing temperature again increased to 240°F, the dragging disappeared. This mix appeared to compact adequately.

After this asphalt binder composition was mixed with aggregate, applied and compacted, the pavement densities were determined using standard industry procedures. The following density was measured from a randomly selected sample – 93.0% of
15 maximum theoretical density. The following density results were determined: 92.7% on the shoulder, 93.0% in the region where the mix was sticking, 93.4%, 93.5% and 93.3% at other locations on the pavement when the mixing temperature was back in the 230-
240°F range. For this project shoulder density minimum requirements were 92.0% of maximum theoretical density and mainline pavement minimum density requirements
20 were 93.0% of maximum theoretical density.

Example 11

A laboratory mix was produced using a PG 70-22 binder modified with SBS (styrene butadiene styrene) polymer. To this blend was added 0.3% polyphosphoric
25 acid and 0.3% PreTech Pavegrip 650 (as an amine based antistrip). The asphalt temperature was 325°F and was being used in an amount of 5.3%. The aggregate was completely dry and heated to 260°F and verified with a certified thermometer. The mixture was put together and mixed in a bucket mixer for approximately 30 to 45 seconds. The coating was 100% and comparable to the hot mix version that was
30 compacted previously. The heat in the bucket dropped below 240°F before the sample was removed from the mixer. The sample was then "cured" for 2 hours at 248°F and then compacted with 37 blows per side on the Marshall Hammer compacting machine.

The resultant sample had about 5.88% average air voids. Data comparing the hot mix version and warm mix version are listed in Table 2.

Table 2

Binder = PG70-22 (SBS)	Mix Temp	Compaction Temp	Blows	Air Voids
0.3% PPA, 0.3% AS	340	300	30	5.49
0.3% PPA, 0.3% AS	340	266	37	5.59
0.3% PPA, 0.3% AS	340	248	37	5.77
0.3% PPA, 0.3% AS	260	248	37	5.88

5

The invention is not to be taken as limited to the details of the above description as modifications and variations thereto may be made. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

CLAIMS:

1. A warm mix asphalt binder composition comprising functionally dry, essentially water-free, non-foamed asphalt binder containing a lubricating additive comprising lubricating surfactant, lubricating non-surfactant, lubricating acid or a combination thereof mixed with uncompacted aggregate to provide aggregate coated with binder and lubricating additive, wherein a warm mix asphalt paving composition is produced at and is at a warm mix temperature at least 30°F lower than a comparison temperature needed to produce a comparison paving composition containing binder-coated aggregate without the lubricating additive, and if the lubricating additive in the warm mix asphalt paving composition is a lubricating wax, then the lubricating wax is less than about 1 wt% of the asphalt binder weight.
2. The warm mix asphalt binder composition of claim 1, wherein the lubricating surfactant comprises ethoxylated tallow amine.
3. The warm mix asphalt binder composition of claim 1, wherein the lubricating non-surfactant comprises montan wax, polymethacrylate, polyacrylate, polyolefin, styrene-maleic ester copolymer, hydrogenated polyisoprene, residual bottoms recovered from refining of recycled engine lubricating oils, or high trans content polyoctenamer reactive polymer.
4. The warm mix asphalt binder composition of claim 1, wherein the lubricating acid comprises polyphosphoric acid.
5. The warm mix asphalt binder composition of any one of claims 1-4, wherein the binder comprises a polymer/acid modified asphalt binder composition or a polymer modified asphalt binder composition.

6. The warm mix asphalt binder composition of any one of claims 1-4 comprising less than 0.5 wt% water.
7. An asphalt binder composition and aggregate mixture comprising the asphalt binder composition of any one of claims 1-6 and aggregate, wherein the aggregate optionally includes up to as much as 100 wt% reclaimed asphalt pavement.
8. A method of making an asphalt binder composition capable of mixing with aggregate and compacting at a warm mix temperature comprising adding a sufficient amount of a lubricating additive comprising lubricating surfactant, lubricating non-surfactant, lubricating acid or a combination thereof to a functionally dry, essentially water-free asphalt binder composition heated to within a warm mix temperature range, so as to lower the aggregate mixing temperature and compacting temperature by at least about 30-50°F compared to a substantially similar asphalt-aggregate mixture that does not contain the lubricating additive, and if the lubricating additive in the warm mix asphalt paving composition is a lubricating wax, then the lubricating wax is less than about 1 wt% of the asphalt binder weight.
9. The method of claim 8, wherein the amount of the lubricating surfactant is about 0.1-0.5 wt%, the amount of the lubricating non-surfactant is less than 2.5 wt%, or the amount of the lubricating acid is about 0.2-1.0 wt%.
10. A method of making bituminous paving comprising the steps of:
 - (a) mixing the asphalt binder composition of any one of claims 1-6 with aggregate, at a temperature of 280°F or lower, to provide a heated paving material,
 - (b) applying the heated paving material to a surface to be paved to provide an applied paving material, and
 - (c) compacting the applied paving material at a temperature 260°F or lower to form a paved surface.

11. The method of claim 8 or 10 wherein the lubricating additive of the asphalt binder composition comprises an ethoxylated tallow amine lubricating surfactant.
12. The method of claim 8 or 10, further comprising adjusting the water content of the asphalt binder composition by injecting a predetermined amount of water into the asphalt binder composition before it is added to the aggregate to form an asphalt-aggregate mixture.
13. The method of claim 8 or 10, further comprising adjusting the water content of the aggregate to a level below 5 wt% before being mixed with the asphalt binder composition.
14. The method of claim 8 or 10, further comprising mixing the asphalt binder composition with the aggregate at a temperature that is 30-50°F lower than the temperature used with a similar asphalt binder composition that does not contain a lubricating surfactant, a lubricating non-surfactant, a lubricating acid or a mixtures thereof.
15. The method of claim 8 or 10, further comprising mixing the asphalt binder composition with the aggregate at a temperature that is more than 50°F lower than the temperature used with a similar asphalt binder composition that does not contain the lubricating additive.
16. The method of claim 8 or 10, further comprising mixing the asphalt binder composition with aggregate at a temperature that is more than 100°F lower than the temperature used with a similar asphalt binder composition that does not contain the lubricating additive.
17. A method of forming a paved surface comprising the steps of:
 - (a) forming a mixture of an aggregate with a functionally dry, essentially water-free warm mix asphalt binder composition heated to within a warm mix temperature range, the warm mix asphalt binder composition including an asphalt binder and a lubricating additive

comprising lubricating surfactant, lubricating non-surfactant, lubricating acid or a combination thereof, and if the lubricating additive in the warm mix asphalt paving composition is a lubricating wax, then the lubricating wax is less than about 1 wt% of the asphalt binder weight;

- (b) hauling the mixture to a site to be paved;
- (c) supplying the mixture to a paving machine;
- (d) using the paving machine to apply the warm mix asphalt binder composition and aggregate mixture to the site to be paved; and
- (e) compacting the mixture to form a paved surface using the warm mix asphalt binder composition and aggregate mixture.

18. The warm mix asphalt binder composition of any one of claims 1-4 comprising a measured normal force of about 2 newtons at a warm mix temperature.

19. The warm mix asphalt binder composition of any one of claims 1-4 comprising a measured normal force of about 1 newton at a warm mix temperature.

20. The warm mix asphalt binder composition of any one of claims 1-4 comprising a measured normal force of about 0.5 newtons at a warm mix temperature.

21. The warm mix asphalt binder composition of claim 1, wherein the lubricating additive is a lubricating surfactant.

22. The warm mix asphalt binder composition of claim 1, wherein the lubricating additive is a lubricating non-surfactant.

23. The warm mix asphalt binder composition of claim 1, wherein the lubricating additive is a lubricating acid.

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FIGURE 1

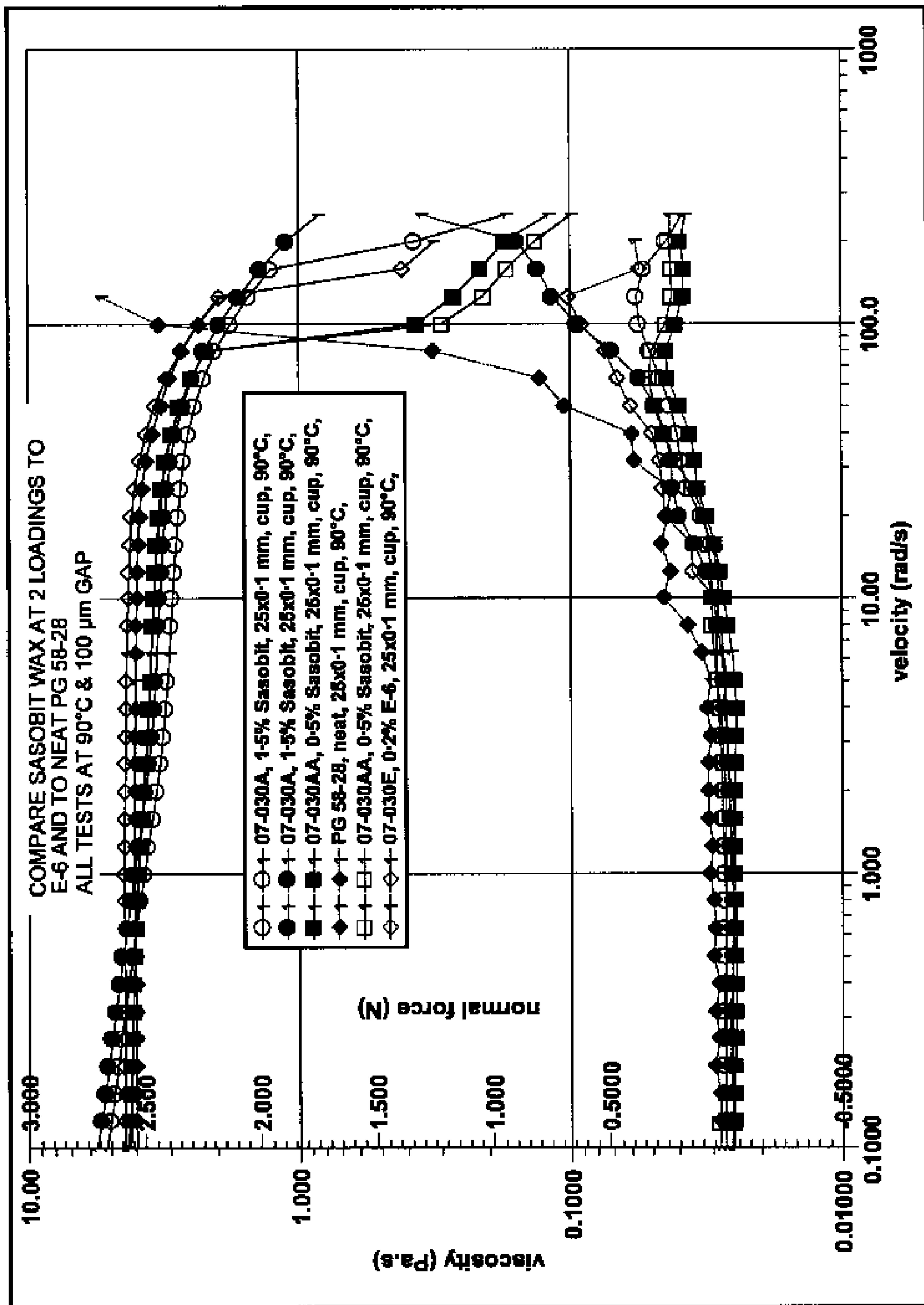
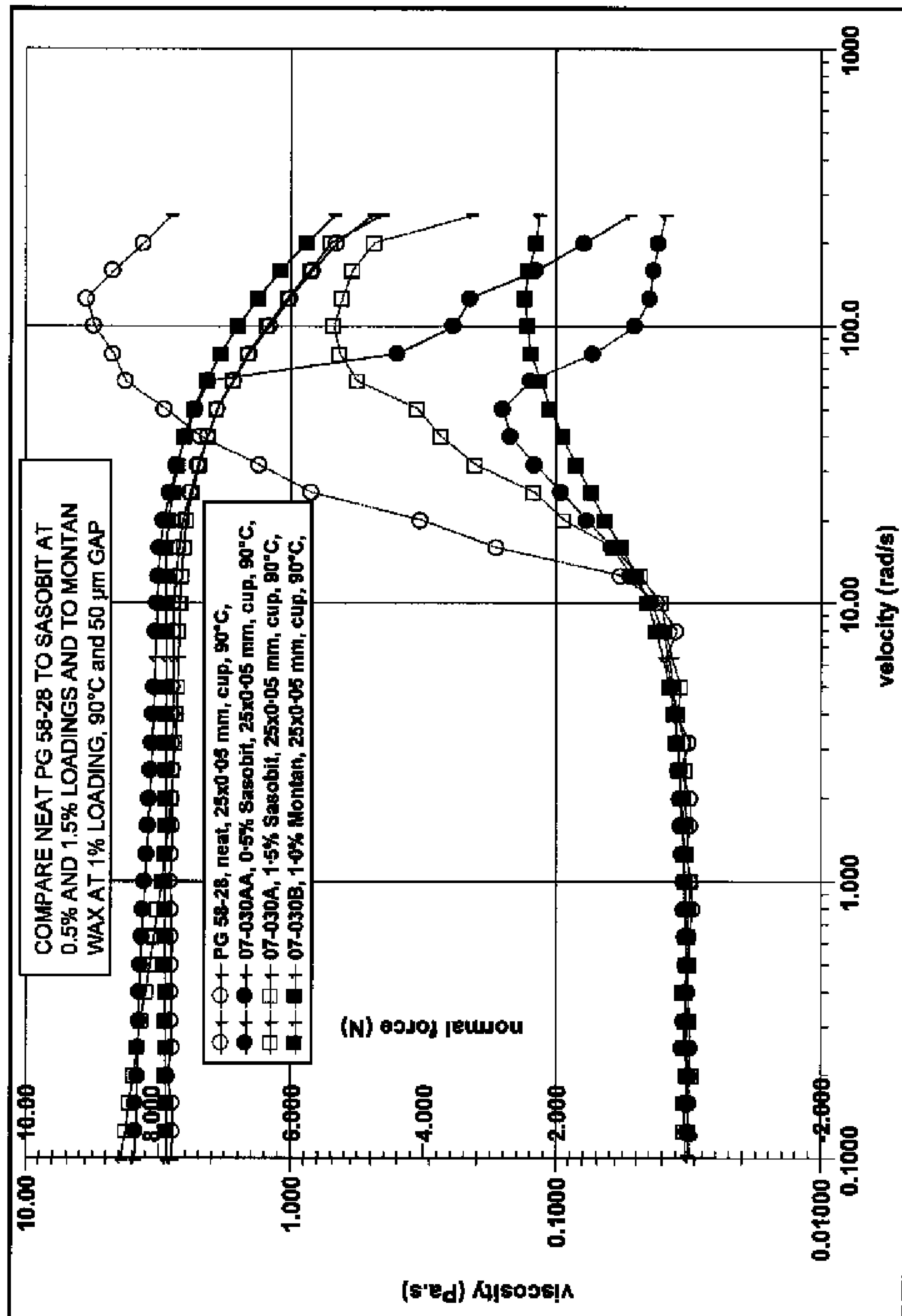


FIGURE 2



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FIGURE 3

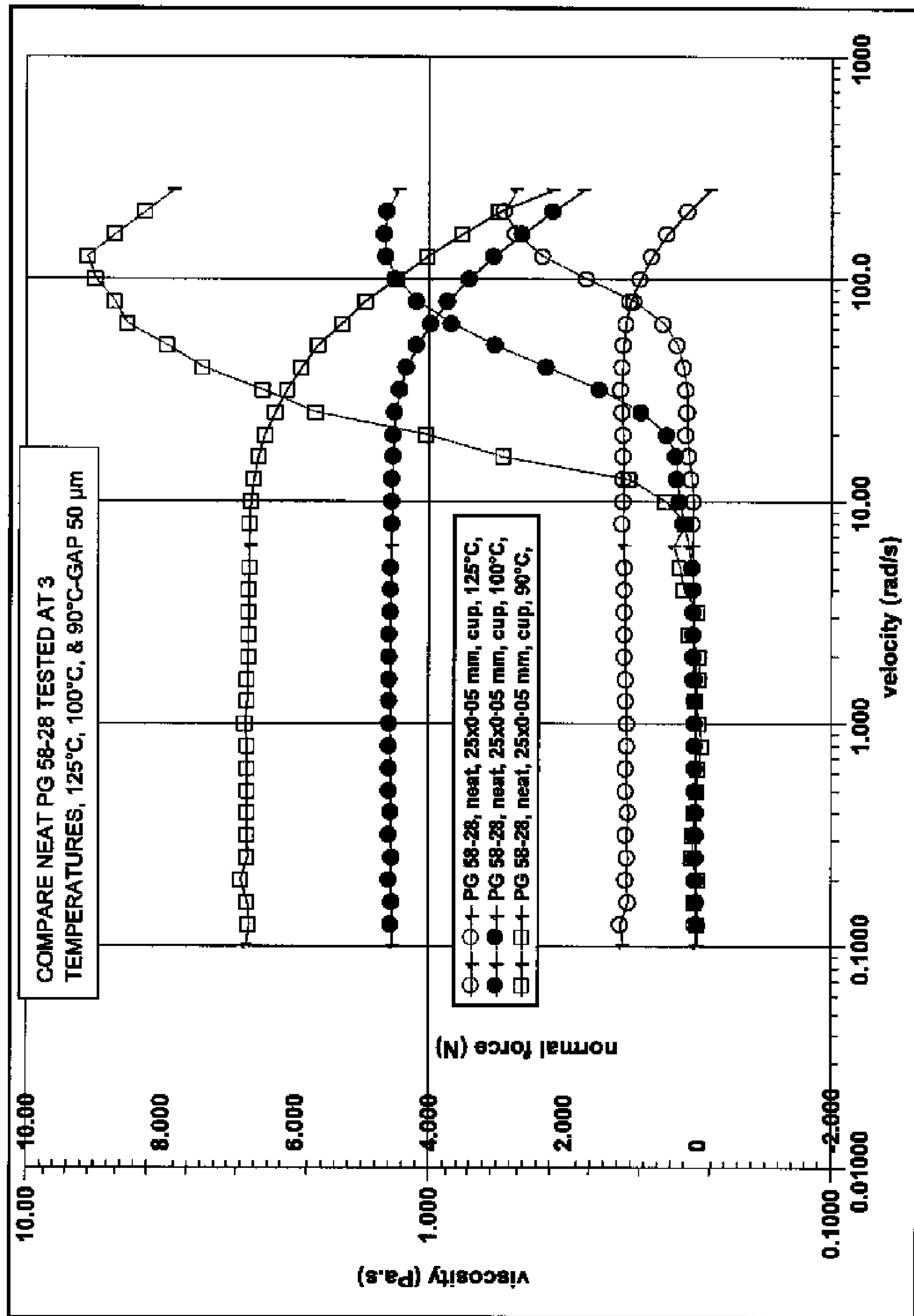


FIGURE 4
COMPARE POLYMER & ACID MODIFIED BINDERS W/ & W/O ADDITIVES TO NEAT 58-28

