

Flow Properties Test Report

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For: SM Stoller
10057-1

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Flow Properties Test Report

SM Stoller

10057-1

1 TEST PROGRAM

The following five samples were received from SM Stoller for testing:

<i>Sample Summary</i>	
Bulk Solid	Description
1	Transitional Tailings GABT-5
2	Slime Tailings GABT-8
3	Slime Tailings GABT-7
4	715 Moab Tailings 22-24'
5	718 Moab Tailings 3-5'

Samples were tested at ambient temperature at their *as received* moisture contents and particle size distributions. For each material, cohesive strength, compressibility, wall friction on three surfaces, and chute angles were measured. Cohesive strength and wall friction tests were run for continuous flow conditions and for flow after 4 hours and overnight storage at rest. From the results, outlet sizes (critical arching and ratholing dimensions), hopper angles that allow mass flow, and minimum angles for material to slide along a chute surface after impact were determined.

2 SUMMARY OF FLOW PROPERTIES

Cohesive strength tests (arching and ratholing dimensions)

The cohesive strength of a bulk material is a function of many variables. Two variables that were included in this program are consolidation pressure and time of storage at rest. Representative values of the cohesive strength of the five materials are tabulated below:

<i>Cohesive Strength</i>			
Material	Time at Rest (hr)	Strength (psf) @ 500 psf Consolidation Pressure	Strength (psf) @ 1000 psf Consolidation Pressure
Transitional Tailings GABT-5			
	0	259	366
	4	269	366
	15	287	395
Slime Tailings GABT-8			
	0	280	537
	4	284	538
	16	288	538

<i>Cohesive Strength (cont'd)</i>			
Material	Time at Rest (hr)	Strength (psf) @ 500 psf	Strength (psf) @ 1000 psf
		Consolidation Pressure	Consolidation Pressure
Slime Tailings GABT-7			
	0	527	736
	4	793	1270
	16	886	1450
715 Moab Tailings 22-24'			
	0	641	763
	4	776	1030
	23	819	1120
718 Moab Tailings 3-5'			
	0	432	538
	4	551	661
	16	643	761

All materials tested are cohesive and have the ability to form a stable rathole if stored in a funnel flow hopper. In addition to this “no flow” problem, funnel flow can cause erratic flow, reduce the live capacity of the hopper, and induce high loads (depending on hopper size) on the structure and downstream equipment due to collapsing ratholes and eccentric flow channels.

Each material should therefore be handled in a mass flow hopper, which provides a first-in-first-out flow sequence, eliminates ratholes and the accompanying stagnant material, and minimizes segregation effects. One of the requirements for achieving mass flow is to size the outlet large enough to prevent arching. (Additional requirements, such as ensuring that the hopper walls are steep enough and sufficiently low in friction, are discussed later.)

The minimum outlet spans required to prevent a stable arch from forming in mass flow hoppers are summarized below:

<i>Minimum Outlet Dimension</i>			
Bulk Material	Time at Rest (hr)	Outlet Size (ft)	
		Conical	Wedge-Shaped
Transitional Tailings GABT-5			
	0	4.1	1.9
	4	5.2	2.6
	Overnight	5.7	2.8
Slime Tailings GABT-8			
	0	2.0	0.9
	4	2.8	1.2
	Overnight	2.9	1.2

<i>Minimum Outlet Dimension (cont'd)</i>			
Material	Time at Rest (hr)	Outlet Size (ft)	
		Conical	Wedge-Shaped
Slime Tailings GABT-7			
	0	15.4	6.9
	4	*	*
	Overnight	*	*
715 Moab Tailings 22-24'			
	0	17.7	8.8
	4	*	*
	Overnight	*	*
718 Moab Tailings 3-5'			
	0	9.6	4.7
	4	13.0	6.3
	Overnight	15.9	7.7

(Dimensions marked by an asterisk (*) signify that unassisted gravity flow is not possible.)

Note that the materials gain cohesive strength and the bin dimensions required to prevent arching increase when the materials are stored at rest over time. If a wedge or a transition hopper is used with a slotted outlet, the outlet length must be at least three times its width in order to use the dimensions given above.

If an overpressure is applied to the material, due to, for example, vibration or impact upon loading, the minimum outlet diameter required to prevent a stable arch from forming in a mass flow hopper increases and in some cases may prevent unassisted gravity flow. Thus, this material should be handled gently to avoid any overpressure.

Compressibility test (bulk density as a function of consolidating pressure)

The bulk density of most bulk solids varies with consolidating pressure. Consideration must be given to using the proper value for such calculations as hopper loads, hopper capacities, and feed density.

The ranges of densities measured in our lab are given below. Densities for specific consolidating pressures are given later in this report.

<i>Density Test Results Summary</i>	
Bulk Material	Measured Range, pcf
Transitional Tailings GABT-5	66 - 110
Slime Tailings GABT-8	49 - 98
Slime Tailings GABT-7	49 - 110
715 Moab Tailings 22-24'	52 - 117
718 Moab Tailings 3-5'	66 - 112

Note that density values can vary significantly if the particle size of the actual material to be handled is different than tested.

Wall friction tests (mass flow angles)

In addition to a properly sized outlet, the design of a mass flow hopper must consider the hopper wall angles, materials of construction, and surface finish. The hopper walls must be steep enough and have sufficiently low friction to allow the material to flow along them. Wall friction angles were determined on the wall materials listed in the following table. As an example of the test results, if a conical hopper with a 2-ft. wide opening were lined or fabricated using the listed wall materials, the corresponding wall angles would be the maximum recommended for continuous mass flow to occur.¹ (Note that this outlet diameter is for comparison only and may be insufficient to prevent cohesive arching.)

<i>Hopper Angles for Mass Flow</i>				
Bulk Material	Wall Material	Angle for Mass Flow (°)		
		0 hr	4 hr	Overnight
Transitional Tailings GABT-5				
	304 #2B Finish Stainless Steel	7	3	2
	TIVAR [®] 88 ²	15	12	10
	Mild Carbon Steel, Mill Finish	1	0*	0*
Slime Tailings GABT-8				
	304 #2B Finish Stainless Steel	4	3	2
	TIVAR [®] 88	19	19	17
	Mild Carbon Steel, Mill Finish	6	0*	0*
Slime Tailings GABT-7				
	304 #2B Finish Stainless Steel	0*	0*	0*
	TIVAR [®] 88	10	7	0*
	Mild Carbon Steel, Mill Finish	0*	0*	0*
715 Moab Tailings 22-24'				
	304 #2B Finish Stainless Steel	0*	0*	0*
	TIVAR [®] 88	8	0*	0*
	Mild Carbon Steel, Mill Finish	0*	0*	0*
718 Moab Tailings 3-5'				
	304 #2B Finish Stainless Steel	7	0*	0*
	TIVAR [®] 88	18	9	0*
	Mild Carbon Steel, Mill Finish	0*	0*	0*

(Hopper angles marked with an asterisk (*) signify that flow along the hopper walls is unlikely.)

¹ Hoppers with elongated outlets require significantly less steep angles than conical hoppers (typically 10° to 12° less steep). Critical angles for such hoppers are given later in this report.

² Ultra high molecular weight polyethylene (UHMW-PE) manufactured by Quadrant Engineering Plastic Products (formerly Poly-Hi Solidur).

Chute tests (critical chute angles)

Tests were run to determine the minimum chute angles required for non-converging flat chutes in order to maintain flow after impact. The results of the chute tests indicate that all materials are very impact pressure sensitive. For example, with impact pressures listed in the following table, the minimum chute angle (from the horizontal) that will cause the material to slide is given.

<i>Minimum Chute Angles</i>			
Bulk Material	Wall Material	Chute Angle ³	
		@ ca. 4 psf	@ ca. 80 psf
Transitional Tailings GABT-5			
	304 #2B Finish Stainless Steel	48	77
	TIVAR [®] 88 ⁴	39	71
	Mild Carbon Steel, Mill Finish	50	83
Slime Tailings GABT-8			
	304 #2B Finish Stainless Steel	41	79
	TIVAR [®] 88	36	66
	Mild Carbon Steel, Mill Finish	45	79
Slime Tailings GABT-7			
	304 #2B Finish Stainless Steel	45	90
	TIVAR [®] 88	42	90
	Mild Carbon Steel, Mill Finish	49	90
715 Moab Tailings 22-24'			
	304 #2B Finish Stainless Steel	66	90
	TIVAR [®] 88	66	90
	Mild Carbon Steel, Mill Finish	63	90
718 Moab Tailings 3-5'			
	304 #2B Finish Stainless Steel	47	72
	TIVAR [®] 88	38	59
	Mild Carbon Steel, Mill Finish	41	69

³ For design purposes, a 5° safety margin has been added to the maximum values determined from the laboratory tests. Also note that increases in impact pressure typically result in steeper required chute angles. A chute angle of 90° indicates that a limit may have been reached during our tests. A vertical chute may not be sufficient to ensure sliding after material impact at the noted pressure.

⁴ Ultra high molecular weight polyethylene (UHMW-PE) manufactured by Quadrant Engineering Plastic Products (formerly Poly-Hi Solidur).

3 GENERAL COMMENTS

All dimensions tabulated in this report represent limiting conditions for flow; therefore, larger outlets, steeper hoppers and chutes are acceptable.

In case you are unfamiliar with the use of this type of data, an Appendix follows the main body of the report. Most of the symbols used in the report are shown in the figures on pages A16 to A18. A Glossary of Terms and Symbols is provided on pages A11 to A13.

Follow-on services

Engineering and design recommendations. This report provides flow properties test results. For the majority of our projects, we are asked to apply our test results and experience in analyzing existing handling systems, to identify the causes of handling problems and to make recommendations for their solutions. We can also provide conceptual designs for the most cost-effective means of avoiding handling problems in new handling systems. If you have questions regarding this report, or how to apply the information contained in the report, please contact Jenike & Johanson.

Bulk solids training. Proper training of personnel involved in solids handling and processing is essential to operating an efficient, reliable, and safe bulk solids handling system. Since the theory of bulk solids handling is seldom a part of formal engineering training, many in industry lack an understanding of why solids handling problems occur and what practical steps can be taken to diagnose, alleviate, or prevent them.

As the leader in this field, Jenike & Johanson provides training for engineers, operators, scientists, formulators, and other personnel on the key elements of bulk solids handling theory and their application to common industrial problems. Training helps to foster greater awareness of operating efficiency, safety, and process improvement, along with an understanding of the reasoning behind our recommendations. Presenting this training at your facility enables us to focus on your company's bulk solids and flow-related concerns, and to discuss related issues in confidence.

Further details about our engineering and educational services can be obtained by visiting www.jenike.com, or by contacting a Jenike & Johanson engineer.

SUMMARY OF TESTS PERFORMED

This report presents various flow property test results as indicated for the following material(s) :

BULK MATERIAL	MATERIAL ID #	DESCRIPTION	PARTICLE SIZE	MOISTURE CONTENT
1	24539	Transitional Tailings GABT-5	As Rec'd	As Rec'd
2	24540	Slime Tailings GABT-8	As Rec'd	As Rec'd
3	24541	Slime Tailings GABT-7	As Rec'd	As Rec'd
4	24542	715 Moab Tailings 22-24'	As Rec'd	As Rec'd
5	24543	718 Moab Tailings 3-5'	As Rec'd	As Rec'd

BULK MATERIAL	TIME hr	TEMPERATURE deg F	SIEVE ANALYSIS	BIN DIM	BULK DENSITY	HOPPER ANGLES	CHUTE ANGLES	FLOW RATE	OTHER
1	0.0	72		X	X	X	X		
	4.0	72		X		X			
	15.0	72		X		X			
2	0.0	72		X	X	X	X		
	4.0	72		X		X			
	16.0	72		X		X			
3	0.0	72		X	X	X	X		
	4.0	72		X		X			
	16.0	72		X		X			
4	0.0	72		X	X	X	X		
	4.0	72		X		X			
	23.0	72		X		X			
5	0.0	72		X	X	X	X		
	4.0	72		X		X			
	16.0	72		X		X			



BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION I. BIN DIMENSIONS FOR DEPENDABLE FLOW

Storage Time at Rest 0.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	4.1	1.9
1.25	5.0	2.3
1.50	6.3	2.9
2.00	8.3	4.0

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	Critical Rathole Diameters, DF (feet)					
			0.5	1.0	2.5	5	10	13 feet
1.00	2.7		15	17	17	17	17	17
1.25	3.2		16	17	17	17	17	17
1.50	3.8		16	17	17	17	17	17
2.00	***		17	17	17	17	17	17

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 4.6 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 4.0 hrs
Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	5.2	2.6
1.25	5.8	2.8
1.50	6.5	3.1
2.00	8.3	4.0

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	13 feet
Critical Rathole Diameters, DF (feet)								
1.00	3.0		25	25	25	25	25	25
1.25	3.4		25	25	25	25	25	25
1.50	3.8		25	25	25	25	25	25
2.00	***		25	25	25	25	25	25

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 4.7 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

- P-FACTOR = overpressure factor
- BC = recommended minimum outlet diameter, conical hopper
- BP = recommended minimum outlet width, slotted or oval outlet
- BF = minimum width of rectangular outlet in a funnel flow bin
- EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 15.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	5.7	2.8
1.25	6.5	3.1
1.50	7.5	3.6
2.00	9.5	4.6

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	13 feet
Critical Rathole Diameters, DF (feet)								
1.00	3.3		26	26	26	26	26	26
1.25	3.8		26	26	26	26	26	26
1.50	4.4		26	26	26	26	26	26
2.00	***		26	26	26	26	26	26

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 5.0 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION II. SOLIDS DENSITY

TEMPERATURE 72 deg F

BULK DENSITY

The bulk density, GAMMA, is a function of the major consolidating pressure, SIGMA1, expressed in terms of effective head, EH.

EH (feet)	0.5	1.0	2.5	5.0	10.0	20.0	40.0	80.0
SIGMA1 (psf)	36.	77.	227.	499.	1054.	2200.	4539.	9366.
GAMMA (pcf)	71.0	77.3	90.9	99.7	105.4	110.0	113.5	117.1

COMPRESSIBILITY PARAMETERS

Bulk density, GAMMA, is a function of the major consolidating pressure SIGMA1, as follows:

For SIGMA1(I-1) < SIGMA1 < SIGMA1(I) :

$$GAMMA = \text{MAX} [GAMMA(I) (SIGMA1/SIGMA1(I))^{BETA(I)}, GAMMAM]$$

Minimum bulk density GAMMAM = 66.5 pcf

I	SIGMA1(I) psf	GAMMA(I) pcf	BETA(I)
1	44.0	71.4	0.02298
2	102.7	80.5	0.14188
3	308.0	95.3	0.15347
4	601.4	101.5	0.09452
5	1188.1	106.2	0.06692
6	1774.8	109.0	0.06338
7	2361.5	110.3	0.04307

BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS FLOW

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 0.0 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.42	0.50	1.00	2.00	4.00	5.30
Width of Oval (feet)	0.24	0.29	0.58	1.11	2.20	2.85
SIGMA (psf)	8.4	9.9	22.	56.	138.	204.
SIGMA1 (psf)	16.7	19.8	40.	80.	180.	266.
Wall Friction Angle PHI-PRIME (deg)	57.	55.	42.	33.	29.	28.
Hopper Angles THETA-P (deg)	7.*	7.*	9.	20.	23.	23.
THETA-C (deg)	0.*	0.*	0.*	7.	12.	13.

* Flow along walls is questionable.

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 4.00 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.06	2.00	4.00	4.17
Width of Oval (feet)	0.61	1.13	2.20	2.29
SIGMA (psf)	21.4	52.2	131.	139.
SIGMA1 (psf)	42.8	82.9	186.	196.
Wall Friction Angle PHI-PRIME (deg)	47.	37.	32.	32.
Hopper Angles THETA-P (deg)	7.*	15.	21.	21.
THETA-C (deg)	0.*	3.	8.	8.

* Flow along walls is questionable.



BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet
STORAGE TIME AT REST 15.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.06	2.00	4.00	4.20
Width of Oval (feet)	0.61	1.13	2.20	2.30
SIGMA (psf)	21.4	51.9	130.	139.
SIGMA1 (psf)	42.8	83.2	187.	199.
Wall Friction Angle PHI-PRIME (deg)	47.	38.	33.	33.
Hopper Angles THETA-P (deg)	7.*	14.	20.	20.
THETA-C (deg)	0.*	2.	7.	8.

* Flow along walls is questionable.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.42	0.50	1.00	2.00	4.00	5.08
Width of Oval (feet)	0.24	0.29	0.56	1.11	2.19	2.74
SIGMA (psf)	8.4	10.8	27.	62.	146.	204.
SIGMA1 (psf)	16.7	19.3	36.	76.	173.	242.
Wall Friction Angle PHI-PRIME (deg)	46.	42.	31.	25.	23.	23.
Hopper Angles THETA-P (deg)	7.*	10.	22.	28.	30.	30.
THETA-C (deg)	0.*	0.*	10.	15.	18.	18.

* Flow along walls is questionable.



BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.89	1.00	2.00	3.87
Width of Oval (feet)	0.50	0.56	1.11	2.13
SIGMA (psf)	21.4	24.9	60.	139.
SIGMA1 (psf)	33.1	37.0	77.	166.
Wall Friction Angle PHI-PRIME (deg)	36.	35.	28.	24.
Hopper Angles THETA-P (deg)	16.	18.	25.	30.
THETA-C (deg)	4.	5.	12.	17.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 15.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.99	1.00	2.00	3.93
Width of Oval (feet)	0.57	0.58	1.11	2.16
SIGMA (psf)	21.4	21.8	58.	139.
SIGMA1 (psf)	39.1	39.5	78.	172.
Wall Friction Angle PHI-PRIME (deg)	42.	42.	31.	26.
Hopper Angles THETA-P (deg)	10.	10.	22.	27.
THETA-C (deg)	0.*	0.*	10.	15.

BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.42	0.50	1.00	2.00	4.00	5.35
Width of Oval (feet)	0.24	0.29	0.58	1.14	2.20	2.88
SIGMA (psf)	8.4	9.9	20.	50.	134.	204.
SIGMA1 (psf)	16.7	19.8	40.	85.	184.	273.
Wall Friction Angle PHI-PRIME (deg)	62.	60.	51.	40.	31.	29.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	13.	22.	22.
THETA-C (deg)	0.*	0.*	0.*	1.	10.	12.

* Flow along walls is questionable.

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.06	2.00	4.00	4.27
Width of Oval (feet)	0.61	1.15	2.21	2.35
SIGMA (psf)	21.4	47.8	126.	139.
SIGMA1 (psf)	42.8	87.5	191.	210.
Wall Friction Angle PHI-PRIME (deg)	53.	42.	35.	35.
Hopper Angles THETA-P (deg)	7.*	9.	17.	17.
THETA-C (deg)	0.*	0.*	5.	5.

* Flow along walls is questionable.

BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
 STORAGE TIME AT REST 15.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.06	2.00	4.00	4.63
Width of Oval (feet)	0.61	1.16	2.27	2.60
SIGMA (psf)	21.4	44.6	111.	139.
SIGMA1 (psf)	42.8	89.2	212.	258.
Wall Friction Angle PHI-PRIME (deg)	62.	57.	45.	41.
Hopper Angles				
THETA-P (deg)	7.*	7.*	8.*	8.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 1: Transitional Tailings GABT-5

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION VI. CHUTE ANGLES

Tests were conducted at the indicated impact pressures, temperatures, and time(s) at rest to determine the angles required for nonconverging chutes in order to maintain flow after material impact. The angle given is the minimum angle from the horizontal that will cause a bed of material to slide on the chute. In general, chutes should be designed with at least a 5 degree safety margin on this angle; if the chute converges, a significantly steeper chute may be required.

Chute Material	Temperature(deg F)		Time at Rest (hours)	Impact Pressure (psf)	Chute Angles (deg) Range	Min. Rec.
	Material	Chute				
304 #2B Finish Stainless Steel Sheet	72	72	0.0	3.7	39 to 43	48.
				42.8	54 to 56	61.
				81.9	63 to 72	77.
				160.1	84 to 90	90.
Tivar 88	72	72	0.0	3.7	31 to 34	39.
				42.8	44 to 48	53.
				81.9	60 to 66	71.
				160.1	71 to 80	85.
Mild Carbon Steel Plate, Mill Finish	72	72	0.0	3.7	42 to 45	50.
				42.8	53 to 62	67.
				81.9	70 to 78	83.
				160.1	90 to 90	90.



BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION I. BIN DIMENSIONS FOR DEPENDABLE FLOW

Storage Time at Rest 0.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	2.0	0.9
1.25	3.8	1.4
1.50	+++	3.8
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	13 feet
Critical Rathole Diameters, DF (feet)								
1.00	3.0		2.4	3.3	6	10	17	20
1.25	***		2.6	3.8	7	12	20	23
1.50	***		2.8	4.2	8	13	22	24
2.00	***		3.2	4.9	9	16	24	29

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 8.4 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 16.7 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 4.0 hrs
 Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	2.8	1.2
1.25	4.6	1.8
1.50	+++	3.8
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	13 feet
Critical Rathole Diameters, DF (feet)								
1.00	3.2		3.0	3.8	6	10	17	20
1.25	***		3.1	4.2	7	12	20	23
1.50	***		3.3	4.6	8	13	22	24
2.00	***		3.7	5	10	16	24	30

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 8.4 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 16.8 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

- P-FACTOR = overpressure factor
- BC = recommended minimum outlet diameter, conical hopper
- BP = recommended minimum outlet width, slotted or oval outlet
- BF = minimum width of rectangular outlet in a funnel flow bin
- EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 16.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	2.9	1.2
1.25	5.2	1.9
1.50	16.3	4.7
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	13 feet
Critical Rathole Diameters, DF (feet)								
1.00	3.8		3.0	3.8	6	11	17	20
1.25	***		3.1	4.2	7	12	20	23
1.50	***		3.3	4.6	8	14	22	24
2.00	***		3.7	5	10	16	24	30

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 8.4 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 16.8 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION II. SOLIDS DENSITY

TEMPERATURE 72 deg F

BULK DENSITY

The bulk density, GAMMA, is a function of the major consolidating pressure, SIGMA1, expressed in terms of effective head, EH.

EH (feet)	0.5	1.0	2.5	5.0	10.0	20.0	40.0	80.0
SIGMA1 (psf)	31.	65.	181.	408.	894.	1924.	4036.	8464.
GAMMA (pcf)	61.4	64.6	72.6	81.7	89.4	96.2	100.9	105.8

COMPRESSIBILITY PARAMETERS

Bulk density, GAMMA, is a function of the major consolidating pressure SIGMA1, as follows:

For SIGMA1(I-1) < SIGMA1 < SIGMA1(I) :

$$GAMMA = \text{MAX} [GAMMA(I) (SIGMA1/SIGMA1(I))^{BETA(I)}, GAMMAM]$$

Minimum bulk density GAMMAM = 49.3 pcf

I	SIGMA1(I) psf	GAMMA(I) pcf	BETA(I)
1	44.0	63.1	0.07370
2	102.7	66.4	0.06056
3	308.0	78.8	0.15629
4	601.4	85.7	0.12533
5	1188.1	92.2	0.10669
6	1774.8	95.7	0.09375
7	2361.5	97.5	0.06408

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS FLOW

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 0.0 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.49	0.50	1.00	2.00	4.00	6.24
Width of Oval (feet)	0.28	0.29	0.58	1.11	2.16	3.33
SIGMA (psf)	8.0	8.3	18.	45.	113.	204.
SIGMA1 (psf)	16.1	16.6	35.	71.	154.	262.
Wall Friction Angle PHI-PRIME (deg)	51.	51.	45.	37.	30.	27.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	16.	21.	25.
THETA-C (deg)	0.*	0.*	0.*	4.	11.	14.

* Flow along walls is questionable.

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 4.00 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.14	2.00	4.00	4.70
Width of Oval (feet)	0.66	1.11	2.16	2.52
SIGMA (psf)	21.1	44.1	111.	138.
SIGMA1 (psf)	40.1	71.3	156.	189.
Wall Friction Angle PHI-PRIME (deg)	44.	38.	31.	30.
Hopper Angles THETA-P (deg)	8.	15.	19.	21.
THETA-C (deg)	0.*	3.	9.	11.

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet
 STORAGE TIME AT REST 16.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.13	2.00	4.00	4.79
Width of Oval (feet)	0.66	1.12	2.16	2.58
SIGMA (psf)	21.1	43.8	108.	138.
SIGMA1 (psf)	39.9	71.5	158.	196.
Wall Friction Angle PHI-PRIME (deg)	44.	38.	33.	31.
Hopper Angles THETA-P (deg)	8.	14.	17.	19.
THETA-C (deg)	0.*	2.	7.	9.

WALL MATERIAL: Tivar 88
 STORAGE TIME AT REST 0.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.38	0.50	1.00	2.00	4.00	5.89
Width of Oval (feet)	0.21	0.28	0.55	1.09	2.15	3.13
SIGMA (psf)	8.0	10.9	24.	55.	128.	204.
SIGMA1 (psf)	9.7	13.2	29.	64.	147.	232.
Wall Friction Angle PHI-PRIME (deg)	25.	24.	23.	22.	20.	19.
Hopper Angles THETA-P (deg)	29.	29.	30.	32.	33.	34.
THETA-C (deg)	16.	16.	18.	19.	21.	23.

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.89	1.00	2.00	4.00	4.29
Width of Oval (feet)	0.49	0.55	1.09	2.15	2.30
SIGMA (psf)	21.1	24.2	55.	127.	138.
SIGMA1 (psf)	25.2	28.7	64.	149.	162.
Wall Friction Angle PHI-PRIME (deg)	24.	23.	22.	21.	21.
Hopper Angles THETA-P (deg)	30.	30.	31.	31.	31.
THETA-C (deg)	17.	17.	19.	20.	20.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 16.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.92	1.00	2.00	4.00	4.33
Width of Oval (feet)	0.51	0.55	1.09	2.15	2.33
SIGMA (psf)	21.1	23.2	54.	126.	138.
SIGMA1 (psf)	27.0	29.4	65.	150.	165.
Wall Friction Angle PHI-PRIME (deg)	28.	27.	24.	23.	23.
Hopper Angles THETA-P (deg)	25.	26.	30.	30.	30.
THETA-C (deg)	13.	13.	17.	18.	19.

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.45	0.50	1.00	2.00	4.00	6.47
Width of Oval (feet)	0.25	0.28	0.56	1.10	2.16	3.46
SIGMA (psf)	8.0	9.1	20.	47.	113.	204.
SIGMA1 (psf)	12.9	14.5	31.	70.	160.	278.
Wall Friction Angle PHI-PRIME (deg)	38.	38.	36.	34.	31.	29.
Hopper Angles THETA-P (deg)	14.	15.	16.	18.	19.	21.
THETA-C (deg)	2.	2.	4.	6.	9.	11.

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.21	2.00	4.00	5.43
Width of Oval (feet)	0.70	1.14	2.23	3.00
SIGMA (psf)	21.1	40.2	96.	138.
SIGMA1 (psf)	42.1	77.6	177.	253.
Wall Friction Angle PHI-PRIME (deg)	62.	58.	49.	43.
Hopper Angles THETA-P (deg)	7.*	8.*	8.*	8.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
 STORAGE TIME AT REST 16.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.21	2.00	4.00	5.43
Width of Oval (feet)	0.70	1.14	2.23	3.00
SIGMA (psf)	21.1	40.2	96.	138.
SIGMA1 (psf)	42.1	77.6	177.	253.
Wall Friction Angle PHI-PRIME (deg)	73.	67.	59.	56.
Hopper Angles				
THETA-P (deg)	7.*	8.*	8.*	8.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 2: Slime Tailings GABT-8

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION VI. CHUTE ANGLES

Tests were conducted at the indicated impact pressures, temperatures, and time(s) at rest to determine the angles required for nonconverging chutes in order to maintain flow after material impact. The angle given is the minimum angle from the horizontal that will cause a bed of material to slide on the chute. In general, chutes should be designed with at least a 5 degree safety margin on this angle; if the chute converges, a significantly steeper chute may be required.

Chute Material	Temperature(deg F)		Time at Rest (hours)	Impact Pressure (psf)	Chute Angles (deg) Range	Min. Rec.
	Material	Chute				
304 #2B Finish Stainless Steel Sheet	72	72	0.0	3.0	34 to 36	41.
				42.1	52 to 56	61.
				81.2	54 to 74	79.
				159.4	69 to 82	87.
Tivar 88	72	72	0.0	3.0	28 to 31	36.
				42.1	49 to 53	58.
				81.2	54 to 61	66.
				159.4	60 to 67	72.
Mild Carbon Steel Plate, Mill Finish	72	72	0.0	3.0	36 to 40	45.
				42.1	60 to 67	72.
				81.2	68 to 74	79.
				159.4	72 to 85	90.



BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION I. BIN DIMENSIONS FOR DEPENDABLE FLOW

Storage Time at Rest 0.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	15.4	6.9
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	Critical Rathole Diameters, DF (feet)				
			0.5	1.0	2.5	5	10 feet
1.00	***		14	18	18	18	18
1.25	***		14	20	20	20	20
1.50	***		14	22	22	22	22
2.00	***		14	26	26	26	26

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 8.6 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 17.1 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 4.0 hrs
Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	+++	***
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	Critical Rathole Diameters, DF (feet)				
			0.5	1.0	2.5	5	10 feet
1.00	***		14	18	18	20	30
1.25	***		14	20	20	22	35
1.50	***		14	22	22	24	40
2.00	***		14	26	26	28	49

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 14.9 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 29.7 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

- P-FACTOR = overpressure factor
- BC = recommended minimum outlet diameter, conical hopper
- BP = recommended minimum outlet width, slotted or oval outlet
- BF = minimum width of rectangular outlet in a funnel flow bin
- EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 16.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	+++	***
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10 feet
Critical Rathole Diameters, DF (feet)							
1.00	***		14	18	18	22	35
1.25	***		15	20	20	25	41
1.50	***		15	22	22	27	46
2.00	***		15	26	26	32	58

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 17.1 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 34.1 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION II. SOLIDS DENSITY

TEMPERATURE 72 deg F

BULK DENSITY

The bulk density, GAMMA, is a function of the major consolidating pressure, SIGMA1, expressed in terms of effective head, EH.

EH (feet)	0.5	1.0	2.5	5.0	10.0	20.0	40.0	80.0
SIGMA1 (psf)	29.	64.	195.	450.	1006.	2182.	4569.	9569.
GAMMA (pcf)	58.5	64.0	78.1	89.9	100.6	109.1	114.2	119.6

COMPRESSIBILITY PARAMETERS

Bulk density, GAMMA, is a function of the major consolidating pressure SIGMA1, as follows:

For SIGMA1(I-1) < SIGMA1 < SIGMA1(I) :

$$GAMMA = \text{MAX} [GAMMA(I) (SIGMA1/SIGMA1(I))^{BETA(I)}, GAMMAM]$$

Minimum bulk density GAMMAM = 48.8 pcf

I	SIGMA1(I) psf	GAMMA(I) pcf	BETA(I)
1	44.0	60.0	0.06098
2	102.7	69.4	0.17231
3	308.0	84.9	0.18329
4	601.4	94.0	0.15298
5	1188.1	102.9	0.13243
6	1774.8	107.7	0.11381
7	2361.5	109.6	0.06230

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS FLOW

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 0.0 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.51	1.00	2.00	4.00	6.25
Width of Oval (feet)	0.29	0.58	1.15	2.22	3.46
SIGMA (psf)	8.1	16.7	40.	113.	204.
SIGMA1 (psf)	16.2	33.3	73.	149.	251.
Wall Friction Angle PHI-PRIME (deg)	70.	58.	43.	30.	26.
Hopper Angles THETA-P (deg)	7.*	7.*	9.	23.	28.
THETA-C (deg)	0.*	0.*	0.*	11.	15.

* Flow along walls is questionable.

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 4.00 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.25	2.00	4.00	4.72
Width of Oval (feet)	0.72	1.16	2.23	2.62
SIGMA (psf)	21.2	39.3	111.	138.
SIGMA1 (psf)	42.3	73.1	151.	182.
Wall Friction Angle PHI-PRIME (deg)	54.	43.	31.	29.
Hopper Angles THETA-P (deg)	7.*	9.	22.	24.
THETA-C (deg)	0.*	0.*	10.	11.

* Flow along walls is questionable.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet
STORAGE TIME AT REST 16.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.25	2.00	4.00	4.78
Width of Oval (feet)	0.72	1.16	2.23	2.66
SIGMA (psf)	21.2	37.1	108.	138.
SIGMA1 (psf)	42.3	74.1	153.	187.
Wall Friction Angle PHI-PRIME (deg)	55.	46.	33.	31.
Hopper Angles THETA-P (deg)	7.*	7.*	20.	22.
THETA-C (deg)	0.*	0.*	7.	10.

* Flow along walls is questionable.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.51	1.00	2.00	4.00	6.01
Width of Oval (feet)	0.29	0.58	1.11	2.21	3.32
SIGMA (psf)	8.1	16.7	48.	122.	204.
SIGMA1 (psf)	16.2	33.3	65.	142.	231.
Wall Friction Angle PHI-PRIME (deg)	63.	49.	31.	22.	20.
Hopper Angles THETA-P (deg)	7.*	7.*	22.	31.	34.
THETA-C (deg)	0.*	0.*	10.	19.	21.

* Flow along walls is questionable.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.25	2.00	4.00	4.52
Width of Oval (feet)	0.72	1.12	2.21	2.50
SIGMA (psf)	21.2	45.9	118.	138.
SIGMA1 (psf)	42.3	66.2	145.	168.
Wall Friction Angle PHI-PRIME (deg)	46.	34.	25.	25.
Hopper Angles THETA-P (deg)	7.*	19.	28.	29.
THETA-C (deg)	0.*	7.	15.	16.

* Flow along walls is questionable.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 16.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.25	2.00	4.00	4.66
Width of Oval (feet)	0.72	1.15	2.22	2.59
SIGMA (psf)	21.2	40.3	113.	138.
SIGMA1 (psf)	42.3	72.0	149.	178.
Wall Friction Angle PHI-PRIME (deg)	53.	42.	30.	28.
Hopper Angles THETA-P (deg)	7.*	10.	23.	25.
THETA-C (deg)	0.*	0.*	11.	12.

* Flow along walls is questionable.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.51	1.00	2.00	4.00	6.77
Width of Oval (feet)	0.29	0.58	1.16	2.27	3.78
SIGMA (psf)	8.1	16.7	37.	99.	204.
SIGMA1 (psf)	16.2	33.3	74.	162.	292.
Wall Friction Angle PHI-PRIME (deg)	71.	62.	51.	39.	33.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	14.	19.
THETA-C (deg)	0.*	0.*	0.*	1.	7.

* Flow along walls is questionable.

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.25	2.00	4.00	5.89
Width of Oval (feet)	0.72	1.16	2.31	3.40
SIGMA (psf)	21.2	37.1	86.	138.
SIGMA1 (psf)	42.3	74.1	172.	277.
Wall Friction Angle PHI-PRIME (deg)	69.	61.	51.	46.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	7.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
 STORAGE TIME AT REST 16.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.25	2.00	4.00	5.89
Width of Oval (feet)	0.72	1.16	2.31	3.40
SIGMA (psf)	21.2	37.1	86.	138.
SIGMA1 (psf)	42.3	74.1	172.	277.
Wall Friction Angle PHI-PRIME (deg)	70.	63.	55.	52.
Hopper Angles				
THETA-P (deg)	7.*	7.*	7.*	7.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 3: Slime Tailings GABT-7

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION VI. CHUTE ANGLES

Tests were conducted at the indicated impact pressures, temperatures, and time(s) at rest to determine the angles required for nonconverging chutes in order to maintain flow after material impact. The angle given is the minimum angle from the horizontal that will cause a bed of material to slide on the chute. In general, chutes should be designed with at least a 5 degree safety margin on this angle; if the chute converges, a significantly steeper chute may be required.

Chute Material	Temperature(deg F)		Time at Rest (hours)	Impact Pressure (psf)	Chute Angles (deg) Range	Min. Rec.
	Material	Chute				
304 #2B Finish Stainless Steel Sheet	72	72	0.0	3.0	38 to 40	45.
				42.1	65 to 76	81.
				81.2	90 to 90	90.
				159.5	90 to 90	90.
Tivar 88	72	72	0.0	3.0	35 to 37	42.
				42.1	62 to 67	72.
				81.2	90 to 90	90.
				159.5	90 to 90	90.
Mild Carbon Steel Plate, Mill Finish	72	72	0.0	3.0	40 to 44	49.
				42.1	69 to 79	84.
				81.2	90 to 90	90.
				159.5	90 to 90	90.



BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION I. BIN DIMENSIONS FOR DEPENDABLE FLOW

Storage Time at Rest 0.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	17.7	8.8
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	12 feet
Critical Rathole Diameters, DF (feet)								
1.00	***		23	23	23	23	23	23
1.25	***		23	23	23	23	23	23
1.50	***		23	23	23	23	23	23
2.00	***		23	24	24	24	24	24

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 8.9 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 17.7 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 4.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	+++	***
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	12 feet
Critical Rathole Diameters, DF (feet)								
1.00	***		23	24	24	24	24	26
1.25	***		23	26	26	26	26	29
1.50	***		23	29	29	29	29	32
2.00	***		23	33	33	33	33	38

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 12.7 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 25.4 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.



BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 23.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	+++	***
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	10	12 feet
Critical Rathole Diameters, DF (feet)								
1.00	***		23	24	26	26	26	29
1.25	***		23	29	29	29	29	32
1.50	***		23	32	32	32	32	36
2.00	***		23	37	37	37	37	43

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 14.0 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 27.9 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION II. SOLIDS DENSITY

TEMPERATURE 72 deg F

BULK DENSITY

The bulk density, GAMMA, is a function of the major consolidating pressure, SIGMA1, expressed in terms of effective head, EH.

EH (feet)	0.5	1.0	2.5	5.0	10.0	20.0	40.0	80.0
SIGMA1 (psf)	28.	58.	182.	452.	1069.	2337.	4996.	10679.
GAMMA (pcf)	55.4	58.3	72.6	90.4	106.9	116.9	124.9	133.5

COMPRESSIBILITY PARAMETERS

Bulk density, GAMMA, is a function of the major consolidating pressure SIGMA1, as follows:

For $SIGMA1(I-1) < SIGMA1 < SIGMA1(I)$:

$$GAMMA = \text{MAX} [GAMMA(I) (SIGMA1/SIGMA1(I))^{BETA(I)}, GAMMAM]$$

Minimum bulk density GAMMAM = 51.7 pcf

I	SIGMA1(I) psf	GAMMA(I) pcf	BETA(I)
1	44.0	56.0	0.02393
2	102.7	63.1	0.14131
3	308.0	82.7	0.24581
4	601.4	96.6	0.23210
5	1188.1	108.9	0.17569
6	1774.8	114.1	0.11661
7	2361.5	117.0	0.08754

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS FLOW

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 0.0 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.57	1.00	2.00	4.00	6.27
Width of Oval (feet)	0.33	0.58	1.16	2.22	3.46
SIGMA (psf)	8.9	15.7	34.	105.	204.
SIGMA1 (psf)	17.8	31.4	67.	134.	227.
Wall Friction Angle PHI-PRIME (deg)	78.	71.	54.	28.	18.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	25.	36.
THETA-C (deg)	0.*	0.*	0.*	13.	23.

* Flow along walls is questionable.

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 4.00 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.39	2.00	4.00	4.99
Width of Oval (feet)	0.80	1.16	2.26	2.77
SIGMA (psf)	21.9	33.6	92.	139.
SIGMA1 (psf)	43.9	67.2	147.	181.
Wall Friction Angle PHI-PRIME (deg)	71.	62.	38.	29.
Hopper Angles THETA-P (deg)	7.*	7.*	15.	25.
THETA-C (deg)	0.*	0.*	2.	12.

* Flow along walls is questionable.

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet
STORAGE TIME AT REST 23.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.39	2.00	4.00	5.08
Width of Oval (feet)	0.80	1.16	2.36	2.82
SIGMA (psf)	21.9	33.6	90.	139.
SIGMA1 (psf)	43.9	67.2	158.	188.
Wall Friction Angle PHI-PRIME (deg)	73.	65.	41.	31.
Hopper Angles THETA-P (deg)	7.*	7.*	11.	22.
THETA-C (deg)	0.*	0.*	0.*	10.

* Flow along walls is questionable.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.57	1.00	2.00	4.00	6.24
Width of Oval (feet)	0.33	0.58	1.11	2.20	3.41
SIGMA (psf)	8.9	15.7	42.	113.	204.
SIGMA1 (psf)	17.8	31.4	60.	125.	216.
Wall Friction Angle PHI-PRIME (deg)	69.	57.	33.	18.	13.
Hopper Angles THETA-P (deg)	7.*	7.*	20.	36.	41.
THETA-C (deg)	0.*	0.*	8.	23.	28.

* Flow along walls is questionable.

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.39	2.00	4.00	4.83
Width of Oval (feet)	0.80	1.16	2.22	2.67
SIGMA (psf)	21.9	33.6	104.	139.
SIGMA1 (psf)	43.9	67.2	135.	168.
Wall Friction Angle PHI-PRIME (deg)	62.	52.	28.	24.
Hopper Angles				
THETA-P (deg)	7.*	7.*	25.	29.
THETA-C (deg)	0.*	0.*	12.	17.

* Flow along walls is questionable.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 23.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.39	2.00	4.00	4.84
Width of Oval (feet)	0.80	1.16	2.24	2.68
SIGMA (psf)	21.9	33.6	96.	139.
SIGMA1 (psf)	43.9	67.2	141.	169.
Wall Friction Angle PHI-PRIME (deg)	72.	64.	34.	25.
Hopper Angles				
THETA-P (deg)	7.*	7.*	18.	29.
THETA-C (deg)	0.*	0.*	6.	16.

* Flow along walls is questionable.

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.57	1.00	2.00	4.00	7.03
Width of Oval (feet)	0.33	0.58	1.16	2.31	3.93
SIGMA (psf)	8.9	15.7	35.	82.	204.
SIGMA1 (psf)	17.8	31.4	69.	165.	299.
Wall Friction Angle PHI-PRIME (deg)	79.	75.	66.	50.	34.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	7.*	18.
THETA-C (deg)	0.*	0.*	0.*	0.*	6.

* Flow along walls is questionable.

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.39	2.00	4.00	6.08
Width of Oval (feet)	0.80	1.16	2.31	3.51
SIGMA (psf)	21.9	34.7	82.	139.
SIGMA1 (psf)	43.9	69.3	165.	279.
Wall Friction Angle PHI-PRIME (deg)	76.	70.	54.	45.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	7.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
 STORAGE TIME AT REST 23.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.39	2.00	4.00	6.08
Width of Oval (feet)	0.80	1.16	2.31	3.51
SIGMA (psf)	21.9	34.7	82.	139.
SIGMA1 (psf)	43.9	69.3	165.	279.
Wall Friction Angle PHI-PRIME (deg)	79.	74.	59.	49.
Hopper Angles				
THETA-P (deg)	7.*	7.*	7.*	7.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 4: 715 Moab Tailings 22-24'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION VI. CHUTE ANGLES

Tests were conducted at the indicated impact pressures, temperatures, and time(s) at rest to determine the angles required for nonconverging chutes in order to maintain flow after material impact. The angle given is the minimum angle from the horizontal that will cause a bed of material to slide on the chute. In general, chutes should be designed with at least a 5 degree safety margin on this angle; if the chute converges, a significantly steeper chute may be required.

Chute Material	Temperature(deg F)		Time at Rest (hours)	Impact Pressure (psf)	Chute Angles (deg) Range	Min. Rec.
	Material	Chute				
304 #2B Finish Stainless Steel Sheet	72	72	0.0	3.4	58 to 61	66.
				42.5	90 to 90	90.
				81.6	90 to 90	90.
				159.9	90 to 90	90.
Tivar 88	72	72	0.0	3.4	54 to 61	66.
				42.5	73 to 84	89.
				81.6	90 to 90	90.
				159.9	90 to 90	90.
Mild Carbon Steel Plate, Mill Finish	72	72	0.0	3.4	50 to 58	63.
				42.5	90 to 90	90.
				81.6	90 to 90	90.
				159.9	90 to 90	90.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION I. BIN DIMENSIONS FOR DEPENDABLE FLOW

Storage Time at Rest 0.0 hrs

Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	9.6	4.7
1.25	10.6	5.0
1.50	+++	5.7
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	Critical Rathole Diameters, DF (feet)				
			0.5	1.0	2.5	5	9 feet
1.00	5.6		15	16	16	16	16
1.25	***		15	18	18	18	18
1.50	***		15	19	19	19	19
2.00	***		15	22	22	22	22

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 6.0 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 11.9 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor

BC = recommended minimum outlet diameter, conical hopper

BP = recommended minimum outlet width, slotted or oval outlet

BF = minimum width of rectangular outlet in a funnel flow bin

EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 4.0 hrs
Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	13.0	6.3
1.25	+++	6.9
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	9 feet
Critical Rathole Diameters, DF (feet)							
1.00	***		20	20	20	20	20
1.25	***		20	21	21	21	21
1.50	***		20	22	22	22	22
2.00	***		20	25	25	25	25

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 7.1 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 14.3 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

P-FACTOR = overpressure factor
BC = recommended minimum outlet diameter, conical hopper
BP = recommended minimum outlet width, slotted or oval outlet
BF = minimum width of rectangular outlet in a funnel flow bin
EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

Storage Time at Rest 16.0 hrs
Temperature 72 deg F

PART A. BINS WITH UNLIMITED MAXIMUM SIZE

Optimum Mass Flow Dimensions

P-Factor	BC feet	BP feet
1.00	15.9	7.7
1.25	+++	***
1.50	+++	***
2.00	+++	***

Funnel Flow Dimensions

P-Factor	BF (feet)	EH=	0.5	1.0	2.5	5	9 feet
Critical Rathole Diameters, DF (feet)							
1.00	***		24	24	24	24	24
1.25	***		24	24	24	24	24
1.50	***		24	26	26	26	26
2.00	***		24	29	29	29	29

*** Denotes unassisted gravity flow is impossible. However, widths of only up to 8.2 feet were simulated by our tests. If larger widths are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

+++ Denotes unassisted gravity flow is impossible. However, diameters of only up to 16.4 feet were simulated by our tests. If larger diameters are practical for your application, further testing at higher pressures might reveal conditions under which unassisted gravity flow is possible.

TERMS

- P-FACTOR = overpressure factor
- BC = recommended minimum outlet diameter, conical hopper
- BP = recommended minimum outlet width, slotted or oval outlet
- BF = minimum width of rectangular outlet in a funnel flow bin
- EH = effective consolidating head

For detailed explanations of terms see appendix pages A5, A6, and A7.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION II. SOLIDS DENSITY

TEMPERATURE 72 deg F

BULK DENSITY

The bulk density, GAMMA, is a function of the major consolidating pressure, SIGMA1, expressed in terms of effective head, EH.

EH (feet)	0.5	1.0	2.5	5.0	10.0	20.0	40.0	80.0
SIGMA1 (psf)	36.	78.	232.	519.	1094.	2236.	4549.	9252.
GAMMA (pcf)	71.6	77.9	92.9	103.8	109.4	111.8	113.7	115.7

COMPRESSIBILITY PARAMETERS

Bulk density, GAMMA, is a function of the major consolidating pressure SIGMA1, as follows:

For SIGMA1(I-1) < SIGMA1 < SIGMA1(I) :

$$GAMMA = \text{MAX} [GAMMA(I) (SIGMA1/SIGMA1(I))^{BETA(I)}, GAMMAM]$$

Minimum bulk density GAMMAM = 65.5 pcf

I	SIGMA1(I) psf	GAMMA(I) pcf	BETA(I)
1	44.0	72.0	0.03089
2	102.7	80.9	0.13765
3	308.0	97.5	0.16941
4	601.4	105.6	0.11941
5	1188.1	110.0	0.05959
6	1774.8	111.2	0.02748
7	2361.5	111.9	0.02385

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

SECTION III. MAXIMUM HOPPER ANGLES FOR MASS FLOW

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 0.0 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.44	0.50	1.00	2.00	4.00	5.35
Width of Oval (feet)	0.26	0.29	0.58	1.12	2.22	2.96
SIGMA (psf)	8.7	9.9	20.	56.	141.	204.
SIGMA1 (psf)	17.5	19.9	41.	81.	174.	243.
Wall Friction Angle PHI-PRIME (deg)	64.	62.	50.	34.	25.	24.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	19.	28.	30.
THETA-C (deg)	0.*	0.*	0.*	7.	15.	17.

* Flow along walls is questionable.

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet

STORAGE TIME AT REST 4.00 hrs

TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.07	2.00	4.00	4.18
Width of Oval (feet)	0.62	1.16	2.23	2.33
SIGMA (psf)	21.8	44.9	130.	139.
SIGMA1 (psf)	43.6	89.8	182.	191.
Wall Friction Angle PHI-PRIME (deg)	57.	48.	32.	31.
Hopper Angles THETA-P (deg)	7.*	7.*	20.	22.
THETA-C (deg)	0.*	0.*	8.	9.

* Flow along walls is questionable.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: 304 #2B Finish Stainless Steel Sheet
STORAGE TIME AT REST 16.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.07	2.00	4.00	4.26
Width of Oval (feet)	0.62	1.16	2.24	2.38
SIGMA (psf)	21.8	44.9	127.	139.
SIGMA1 (psf)	43.6	89.8	185.	197.
Wall Friction Angle PHI-PRIME (deg)	66.	52.	34.	33.
Hopper Angles				
THETA-P (deg)	7.*	7.*	19.	20.
THETA-C (deg)	0.*	0.*	6.	8.

* Flow along walls is questionable.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.44	0.50	1.00	2.00	4.00	5.19
Width of Oval (feet)	0.26	0.29	0.56	1.11	2.21	2.86
SIGMA (psf)	8.7	9.9	26.	63.	149.	204.
SIGMA1 (psf)	17.5	19.9	37.	75.	167.	227.
Wall Friction Angle PHI-PRIME (deg)	53.	50.	32.	23.	19.	18.
Hopper Angles						
THETA-P (deg)	7.*	7.*	20.	30.	35.	36.
THETA-C (deg)	0.*	0.*	8.	18.	22.	23.

* Flow along walls is questionable.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.03	2.00	3.99
Width of Oval (feet)	0.60	1.11	2.21
SIGMA (psf)	21.8	57.3	139.
SIGMA1 (psf)	41.7	79.6	174.
Wall Friction Angle PHI-PRIME (deg)	44.	32.	27.
Hopper Angles THETA-P (deg)	8.	21.	27.
THETA-C (deg)	0.*	9.	14.

WALL MATERIAL: Tivar 88
STORAGE TIME AT REST 16.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.07	2.00	4.00	4.06
Width of Oval (feet)	0.62	1.15	2.22	2.25
SIGMA (psf)	21.8	48.9	136.	139.
SIGMA1 (psf)	43.6	87.2	178.	181.
Wall Friction Angle PHI-PRIME (deg)	57.	42.	29.	29.
Hopper Angles THETA-P (deg)	7.*	10.	24.	25.
THETA-C (deg)	0.*	0.*	12.	12.

* Flow along walls is questionable.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 0.0 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	0.44	0.50	1.00	2.00	4.00	5.53
Width of Oval (feet)	0.26	0.29	0.58	1.16	2.23	3.07
SIGMA (psf)	8.7	9.9	20.	46.	132.	204.
SIGMA1 (psf)	17.5	19.9	41.	91.	183.	261.
Wall Friction Angle PHI-PRIME (deg)	63.	62.	56.	46.	32.	28.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	7.*	21.	25.
THETA-C (deg)	0.*	0.*	0.*	0.*	9.	13.

* Flow along walls is questionable.

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
STORAGE TIME AT REST 4.00 hrs
TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.07	2.00	4.00	5.08
Width of Oval (feet)	0.62	1.16	2.31	2.94
SIGMA (psf)	21.8	44.9	103.	139.
SIGMA1 (psf)	43.6	89.8	206.	274.
Wall Friction Angle PHI-PRIME (deg)	64.	54.	47.	45.
Hopper Angles THETA-P (deg)	7.*	7.*	7.*	7.
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

MOISTURE CONTENT As Rec'd

WALL MATERIAL: Mild Carbon Steel Plate, Mill Finish
 STORAGE TIME AT REST 16.0 hrs
 TEMPERATURE 72 deg F

HOPPER ANGLES FOR VARIOUS HOPPER SPANS

Dia of Cone (feet)	1.07	2.00	4.00	5.13
Width of Oval (feet)	0.62	1.16	2.31	2.97
SIGMA (psf)	21.8	45.6	104.	139.
SIGMA1 (psf)	43.6	91.2	207.	278.
Wall Friction Angle PHI-PRIME (deg)	71.	62.	54.	52.
Hopper Angles				
THETA-P (deg)	7.*	7.*	7.*	7.*
THETA-C (deg)	0.*	0.*	0.*	0.*

* Flow along walls is questionable.

BULK MATERIAL 5: 718 Moab Tailings 3-5'

PARTICLE SIZE As Rec'd

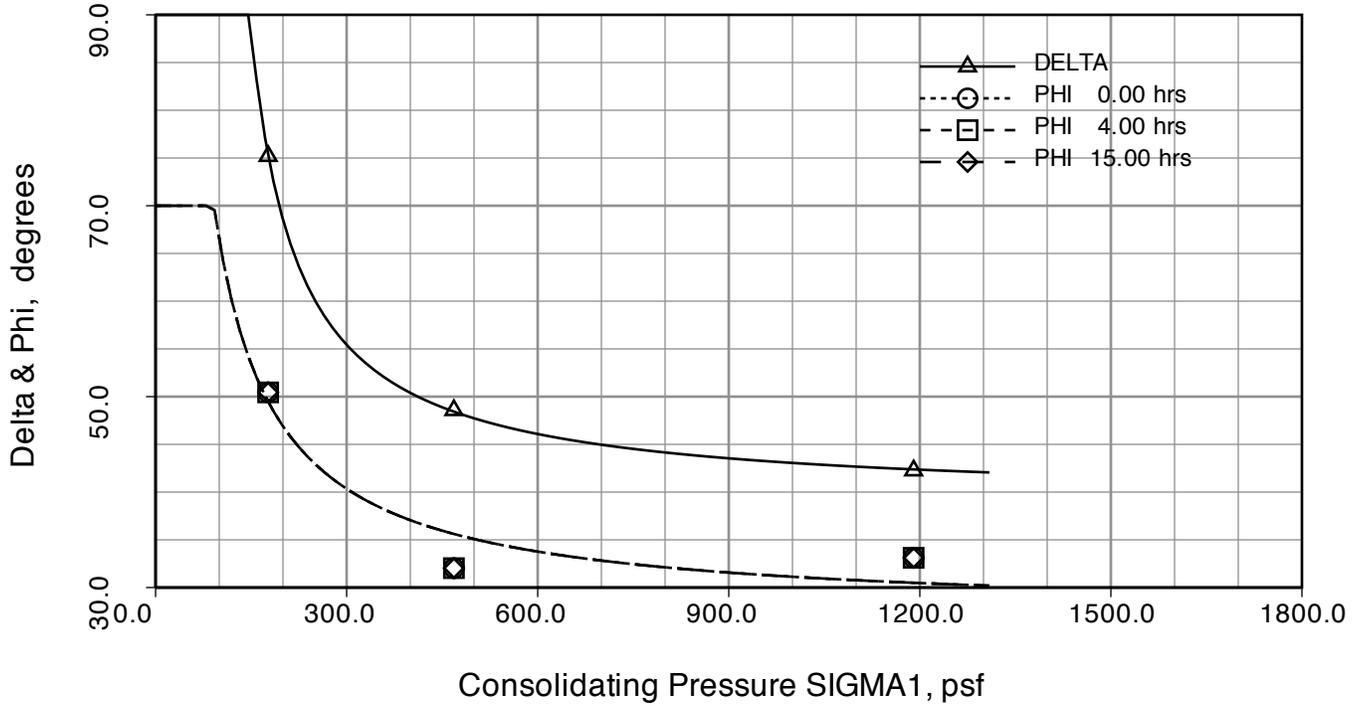
MOISTURE CONTENT As Rec'd

SECTION VI. CHUTE ANGLES

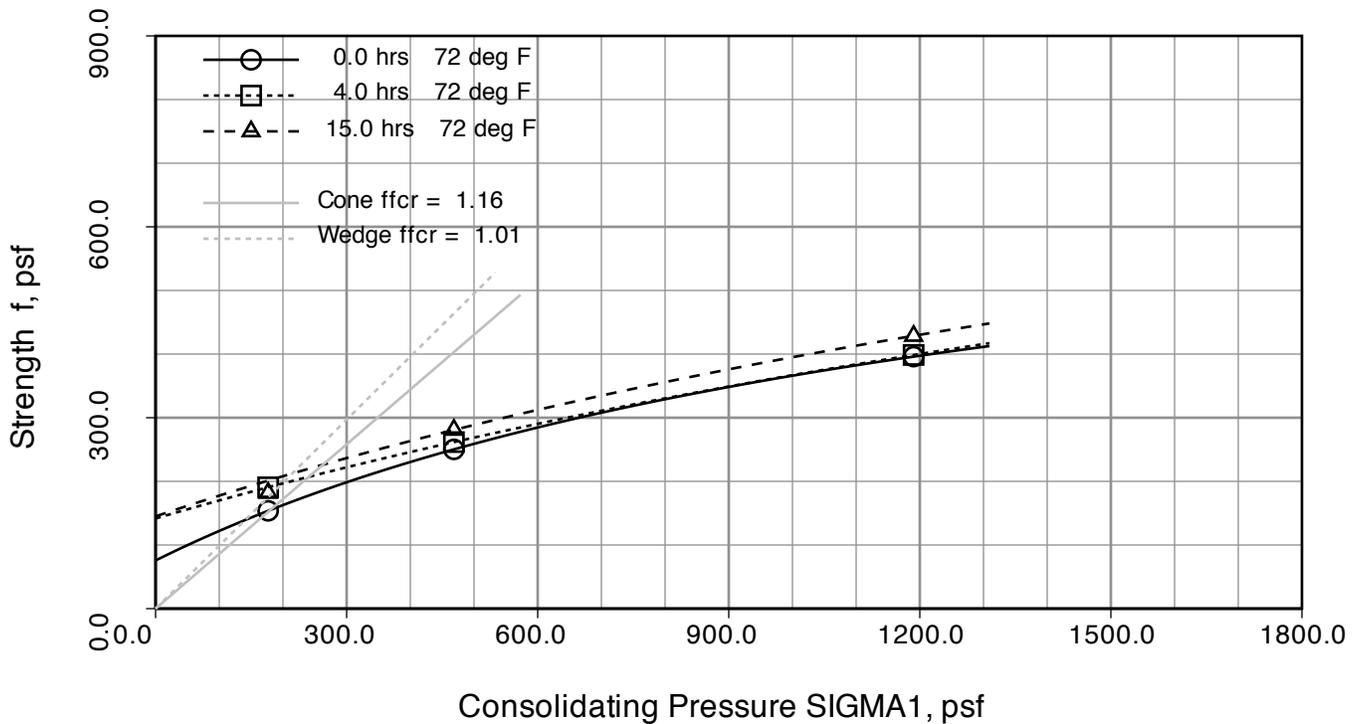
Tests were conducted at the indicated impact pressures, temperatures, and time(s) at rest to determine the angles required for nonconverging chutes in order to maintain flow after material impact. The angle given is the minimum angle from the horizontal that will cause a bed of material to slide on the chute. In general, chutes should be designed with at least a 5 degree safety margin on this angle; if the chute converges, a significantly steeper chute may be required.

Chute Material	Temperature(deg F)		Time at Rest (hours)	Impact Pressure (psf)	Chute Angles (deg) Range	Min. Rec.
	Material	Chute				
304 #2B Finish Stainless Steel Sheet	72	72	0.0	3.8	39 to 42	47.
				42.9	47 to 54	59.
				82.0	63 to 67	72.
				160.3	90 to 90	90.
Tivar 88	72	72	0.0	3.8	30 to 33	38.
				42.9	41 to 46	51.
				82.0	53 to 54	59.
				160.3	73 to 83	88.
Mild Carbon Steel Plate, Mill Finish	72	72	0.0	3.8	34 to 36	41.
				42.9	50 to 52	57.
				82.0	61 to 64	69.
				160.3	80 to 90	90.

DELTA & PHI RELATIONS



FLOW FUNCTION(S)



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

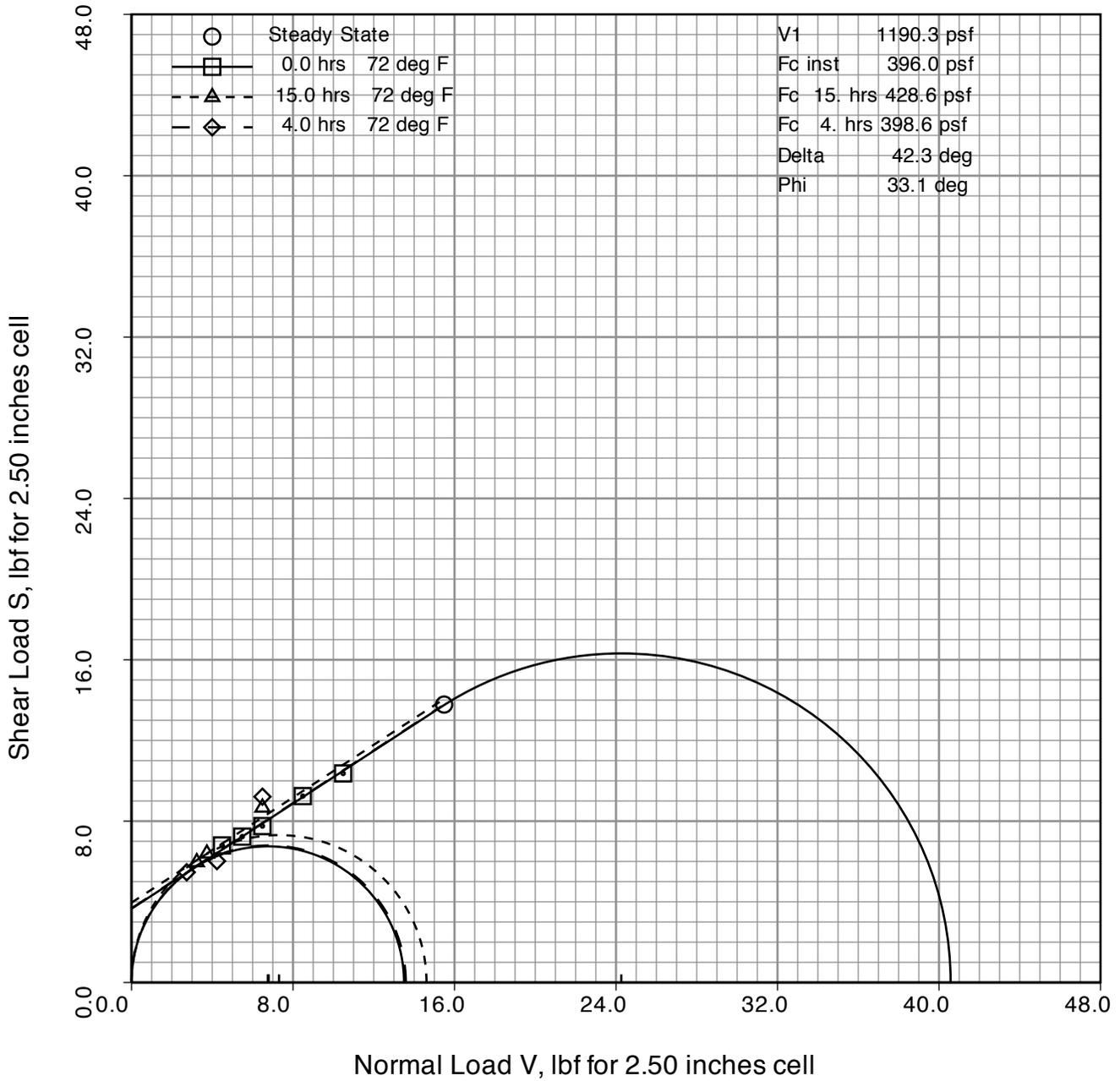
CREATE: 6/03/20

RUN: 6/04/06

JOB#: 10057

ID#: 24539

YIELD LOCUS



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

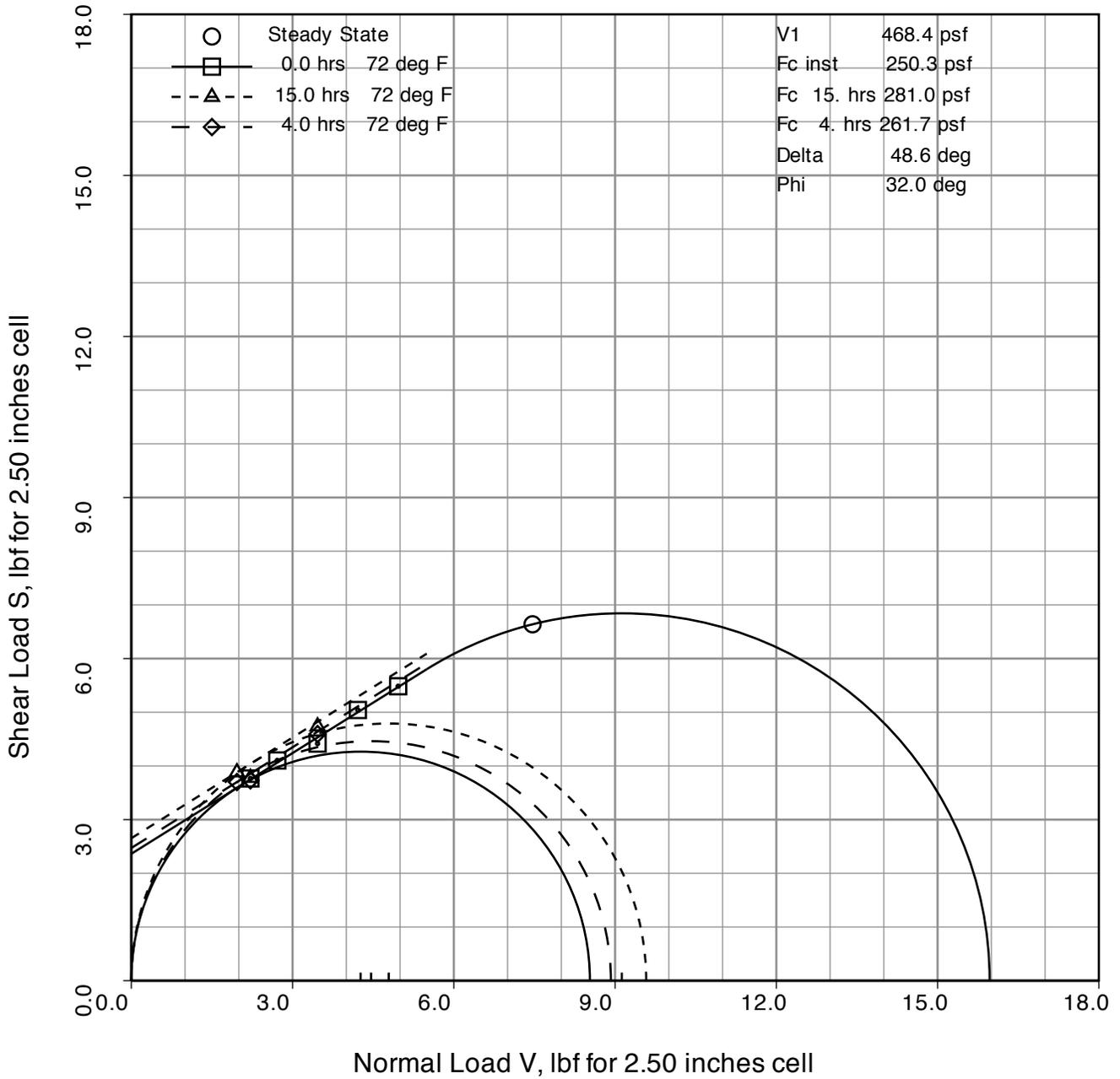
CREATE: 6/03/20

RUN: 6/04/06

JOB#: 10057

ID#: 24539

YIELD LOCUS



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

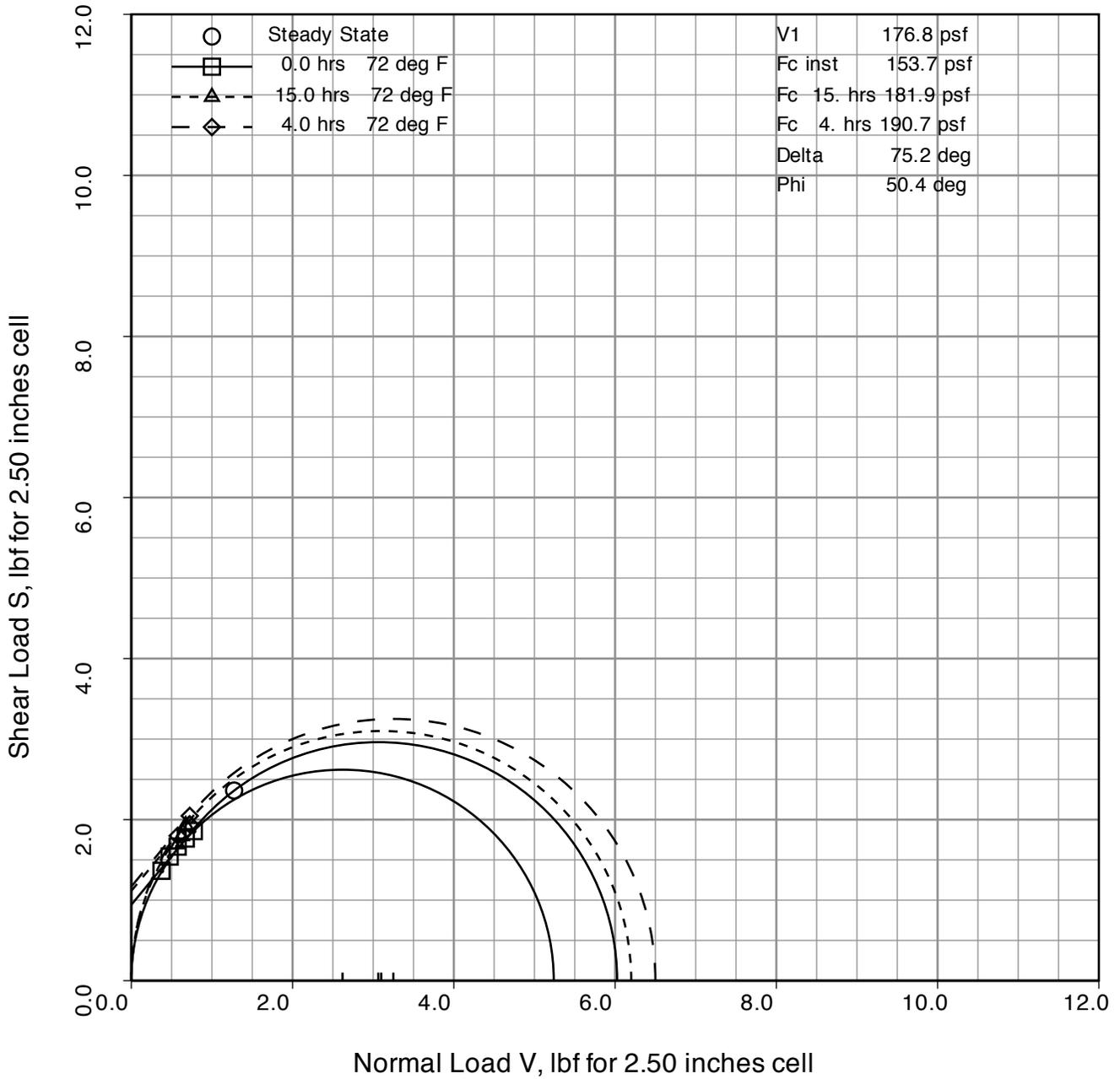
CREATE: 6/03/20

RUN: 6/04/06

JOB#: 10057

ID#: 24539

YIELD LOCUS



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

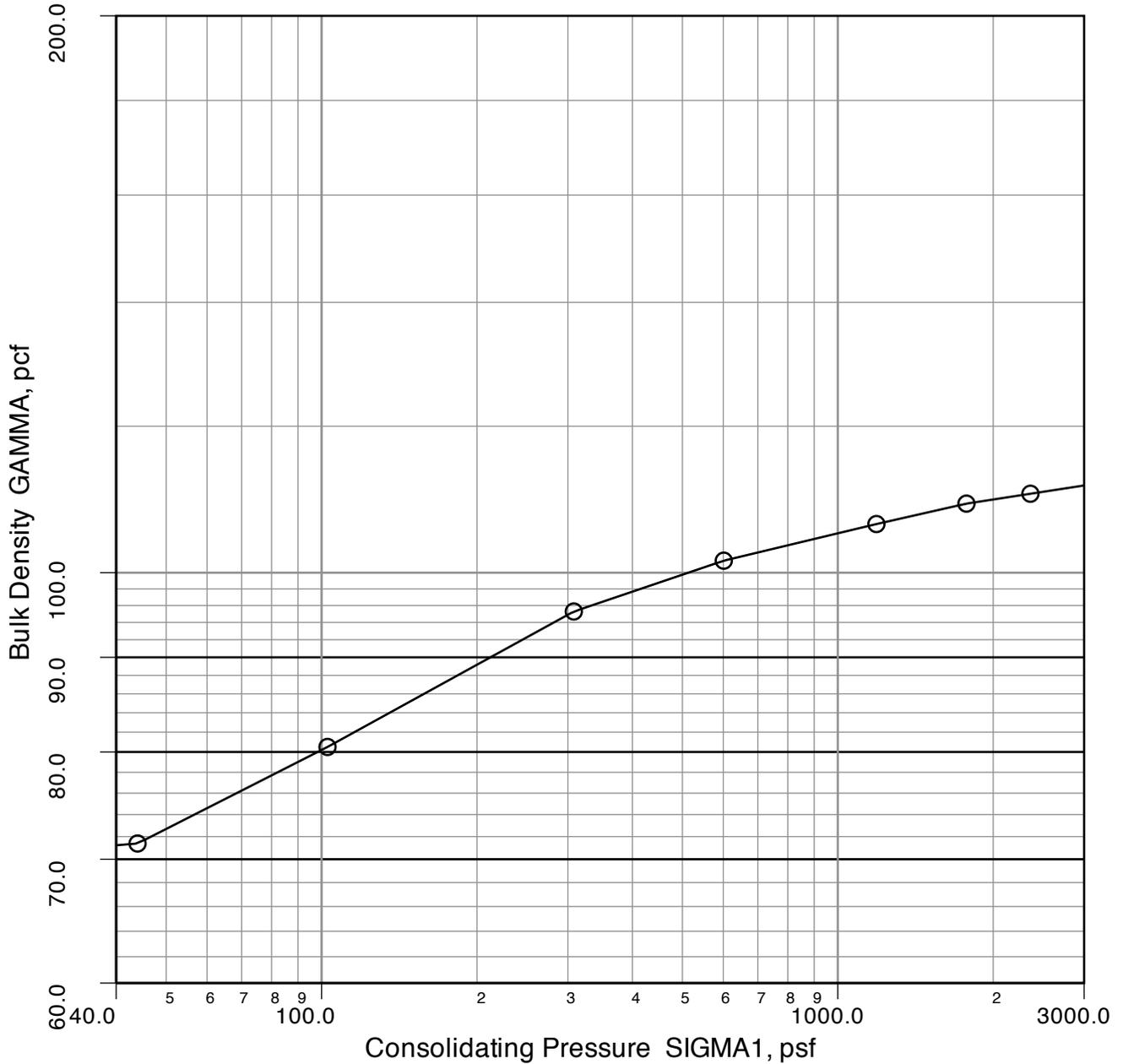
CREATE: 6/03/20

RUN: 6/04/06

JOB#: 10057

ID#: 24539

BULK DENSITY VS. CONSOLIDATING PRESSURE



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

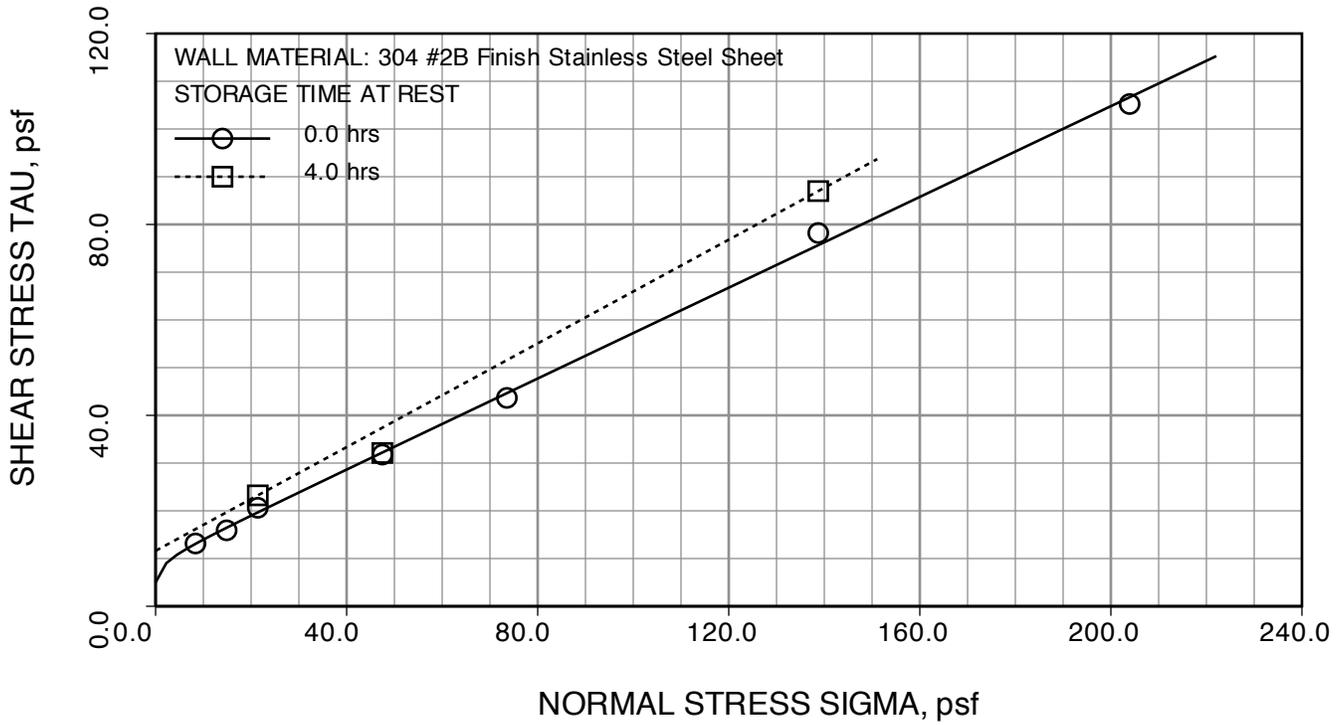
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RUN: 6/04/06

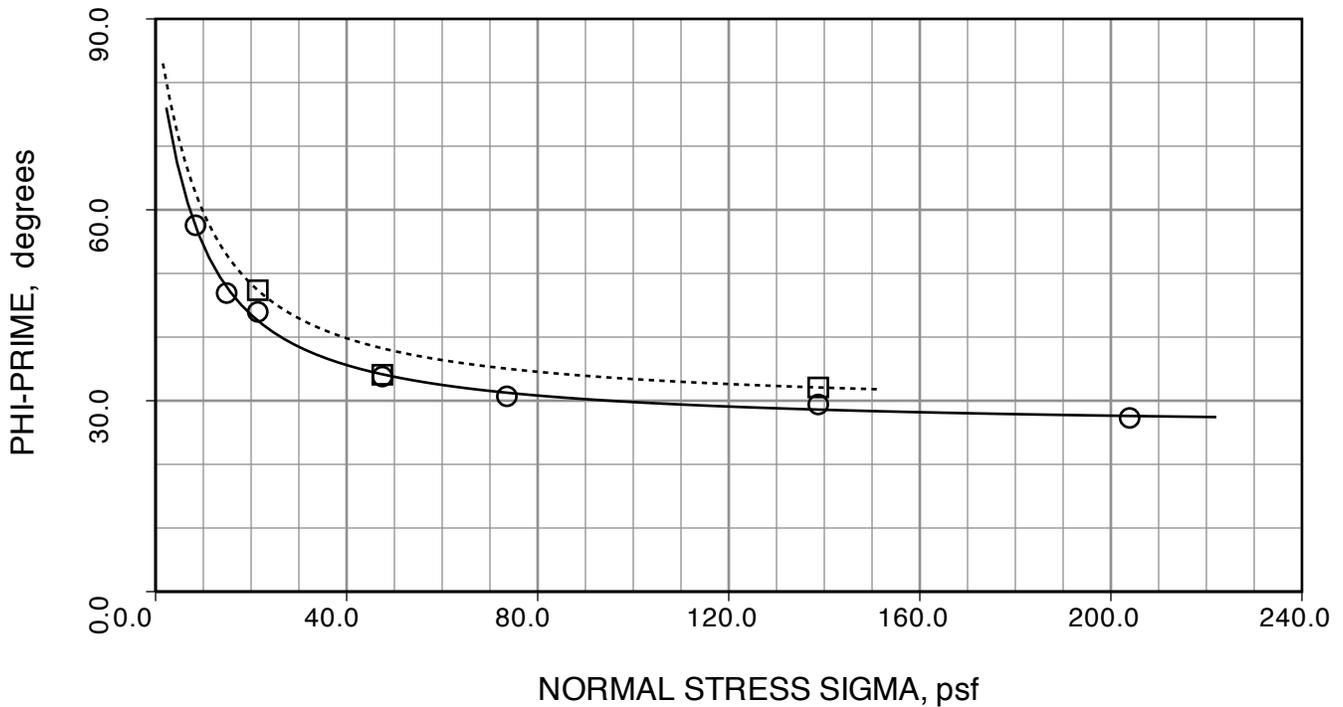
JOB#: 10057

ID#: 24539

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

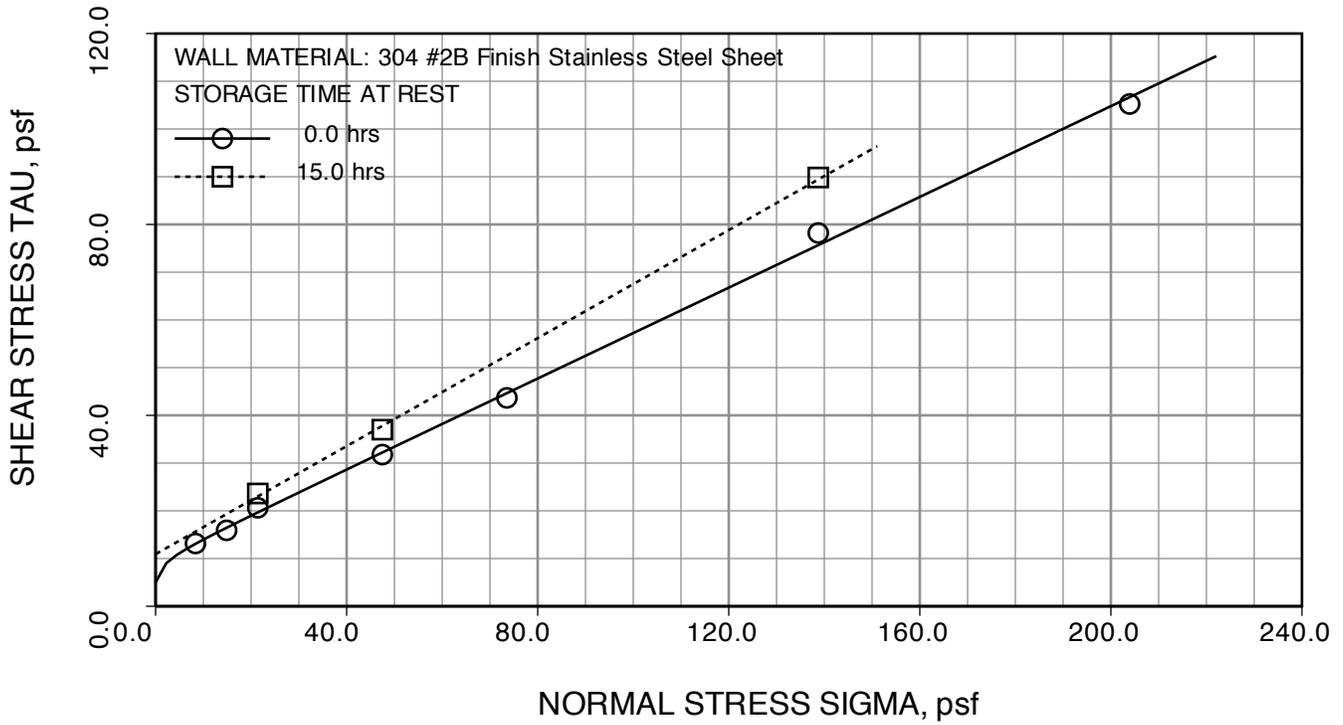
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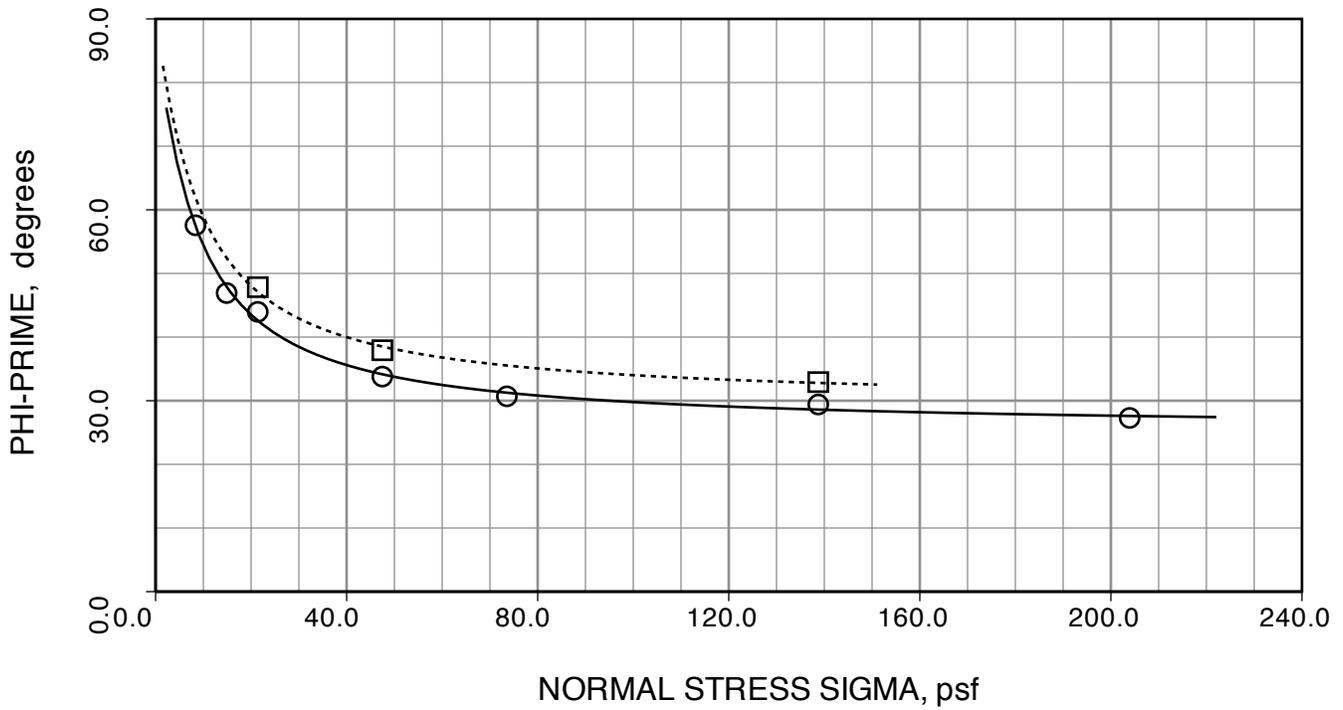
RUN: 6/04/06

ID#: 24539

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

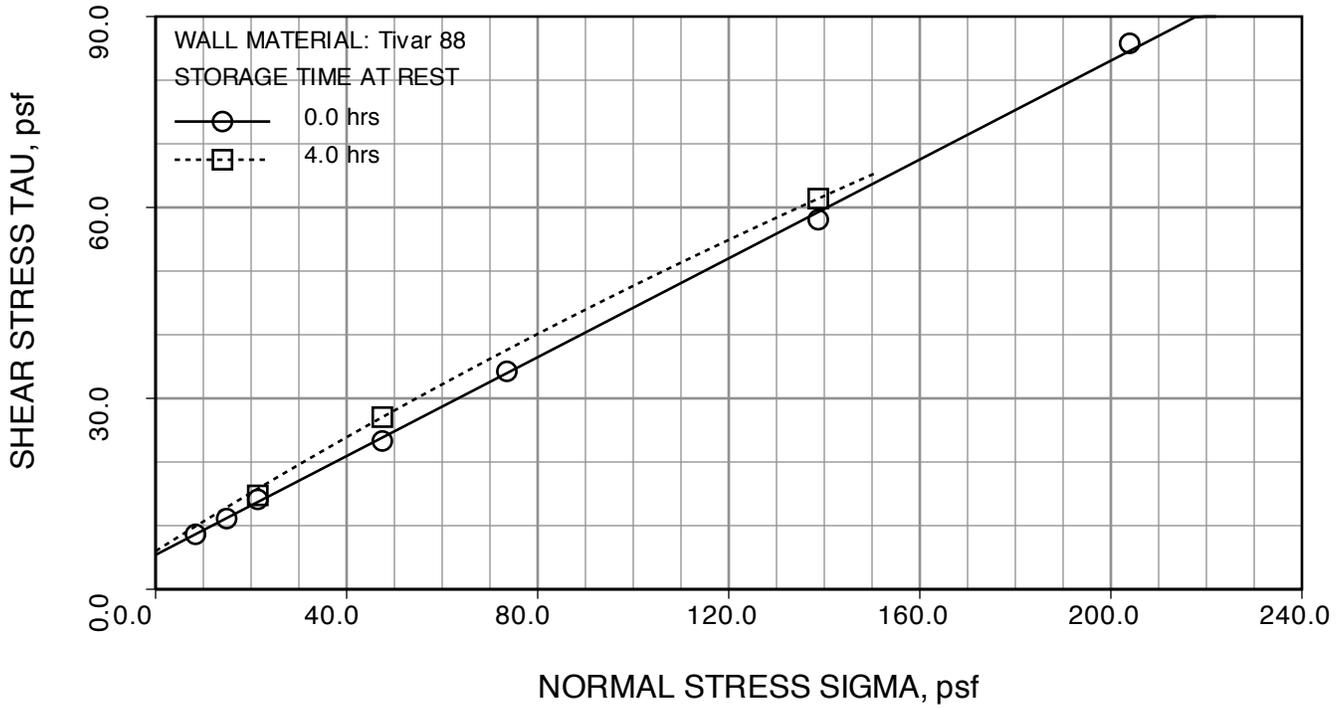
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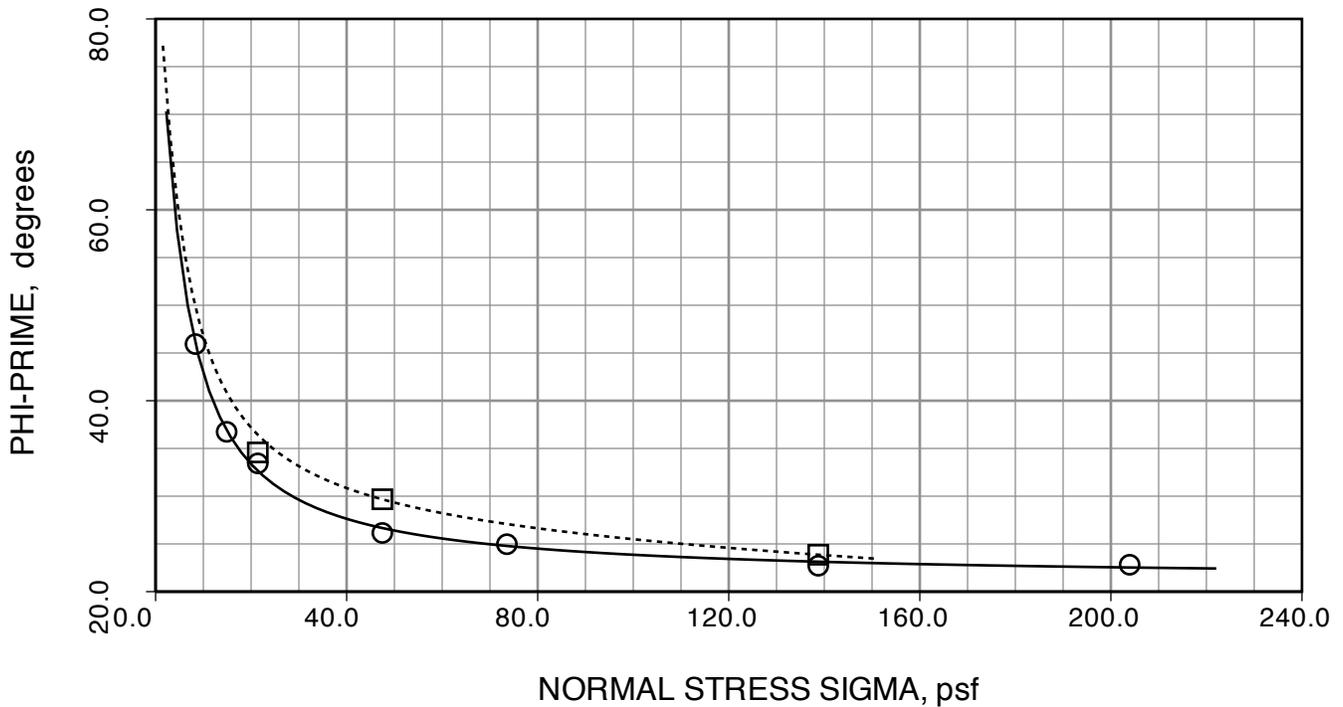
JOB#: 10057

ID#: 24539

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

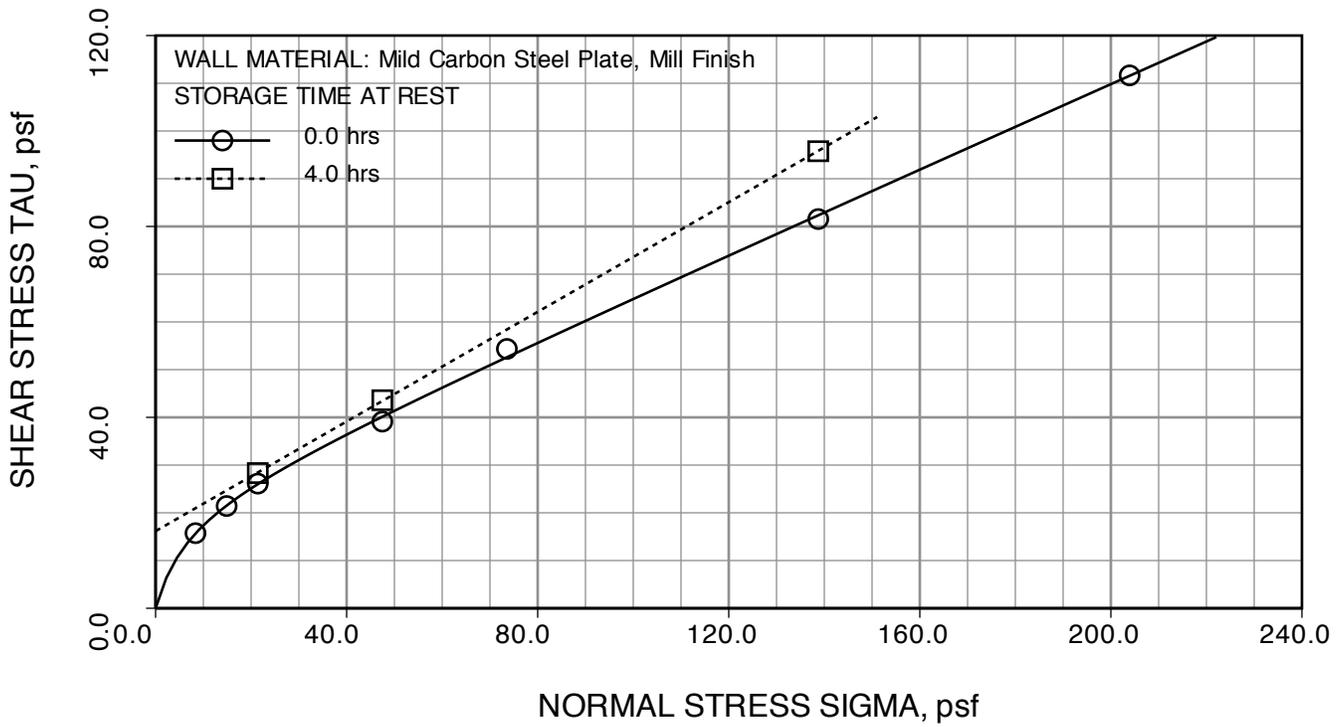
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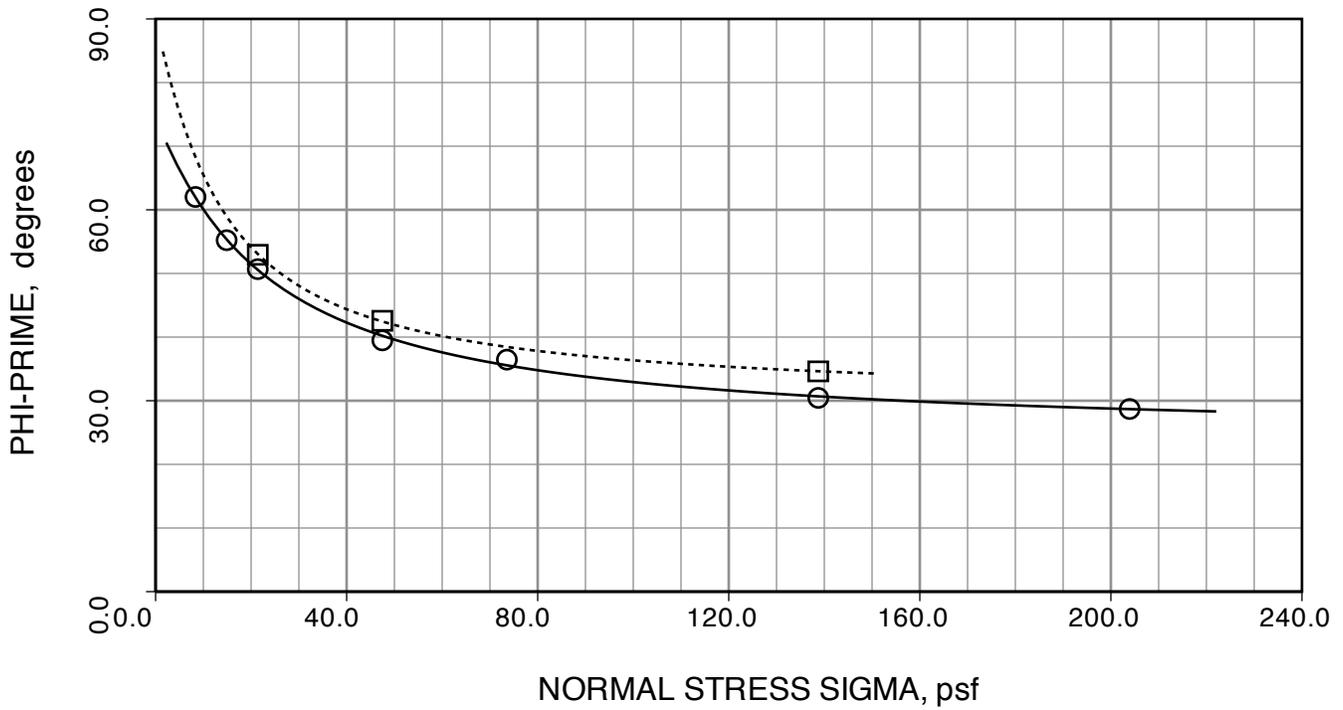
JOB#: 10057

ID#: 24539

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

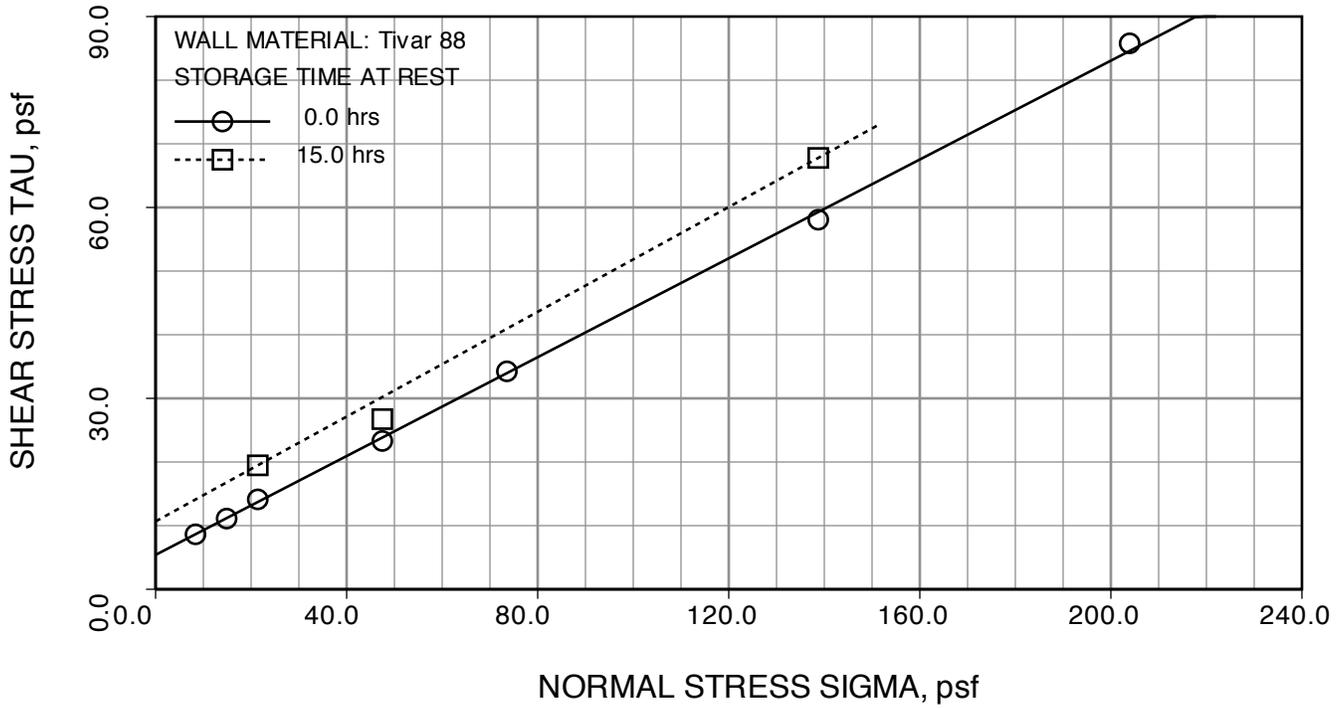
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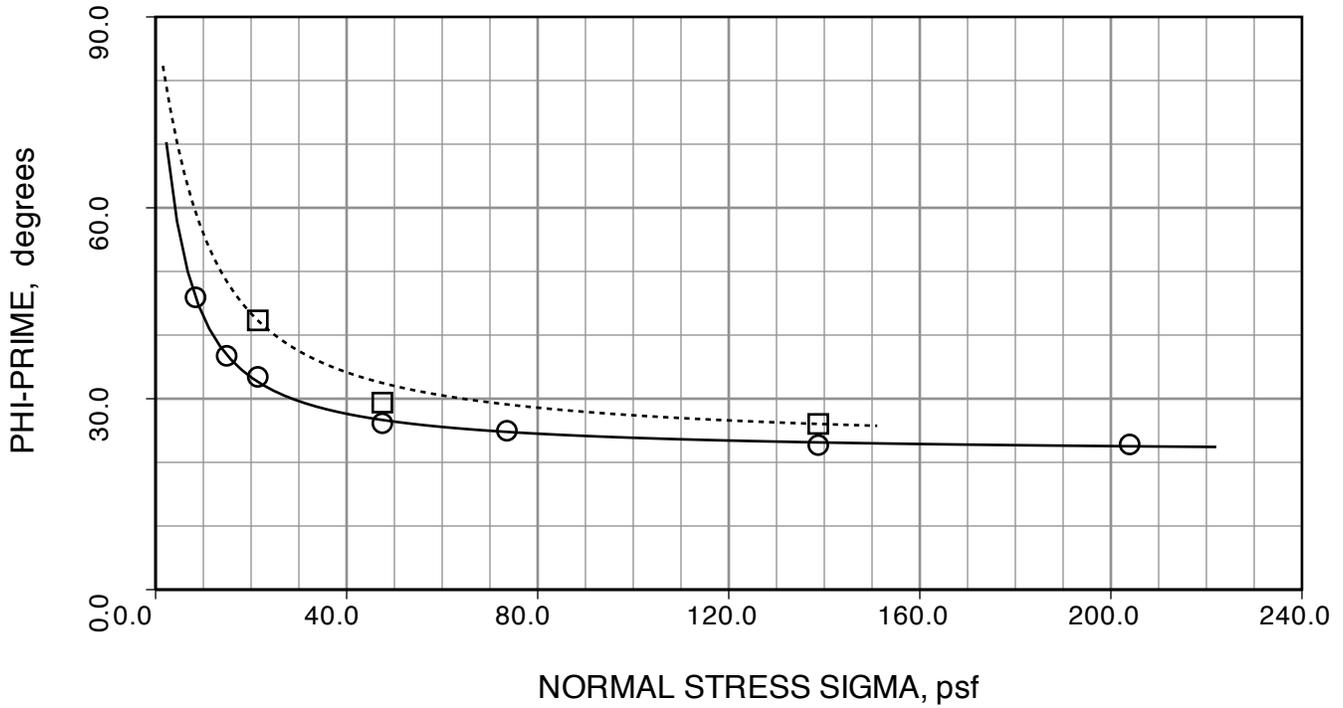
JOB#: 10057

ID#: 24539

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Transitional Tailings GABT-5

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

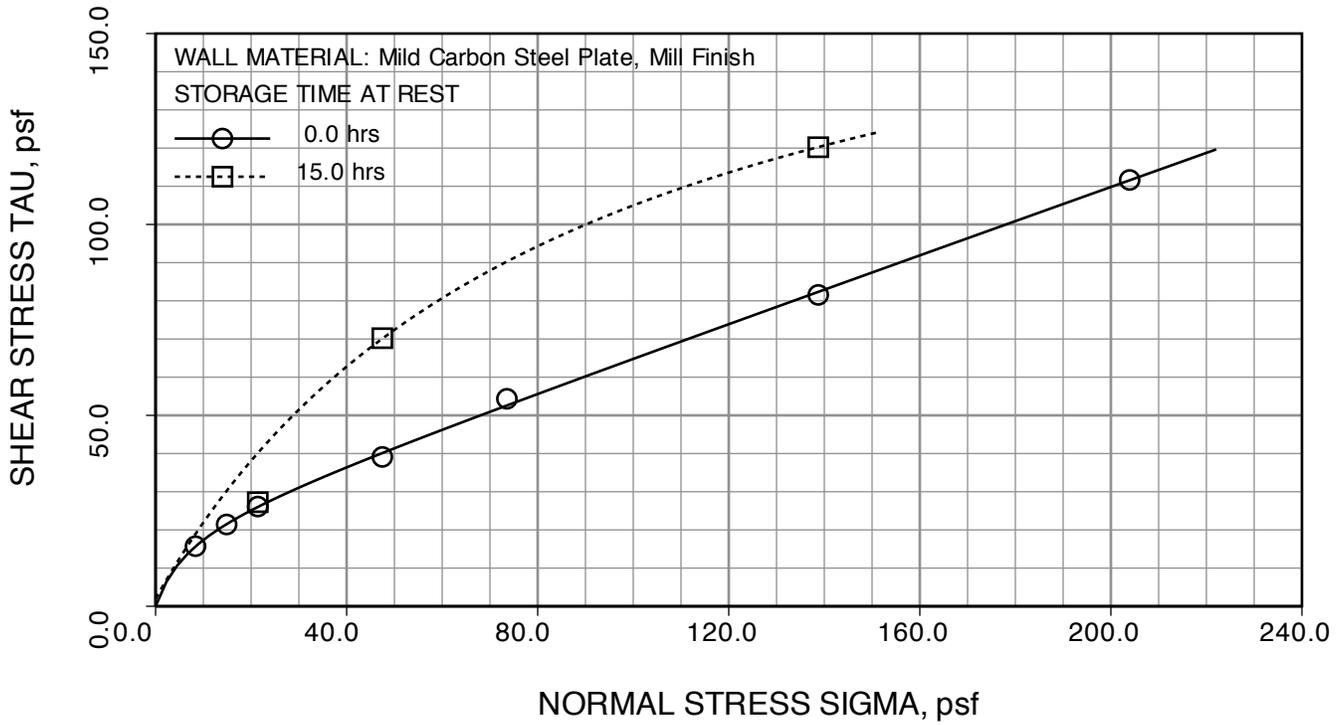
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RUN: 6/04/06

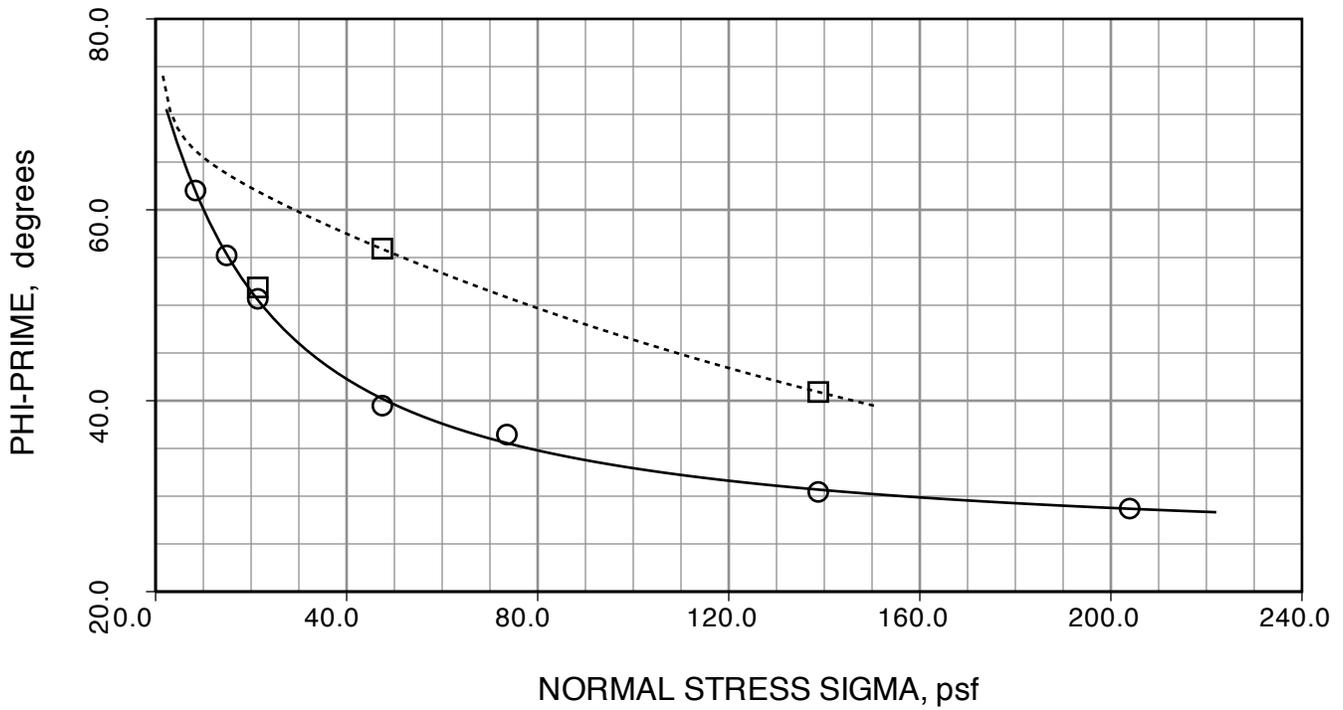
JOB#: 10057

ID#: 24539

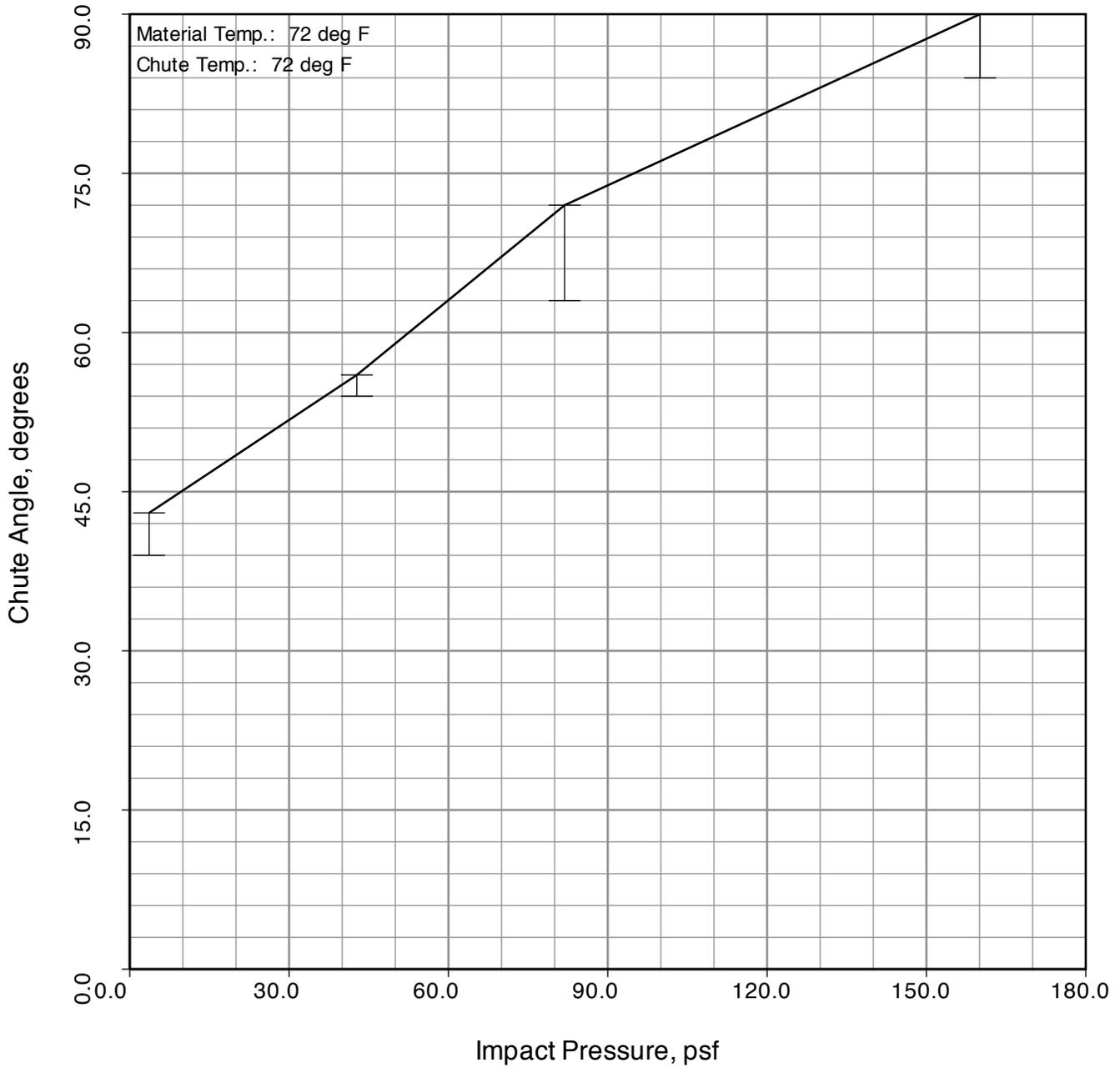
WALL YIELD LOCUS



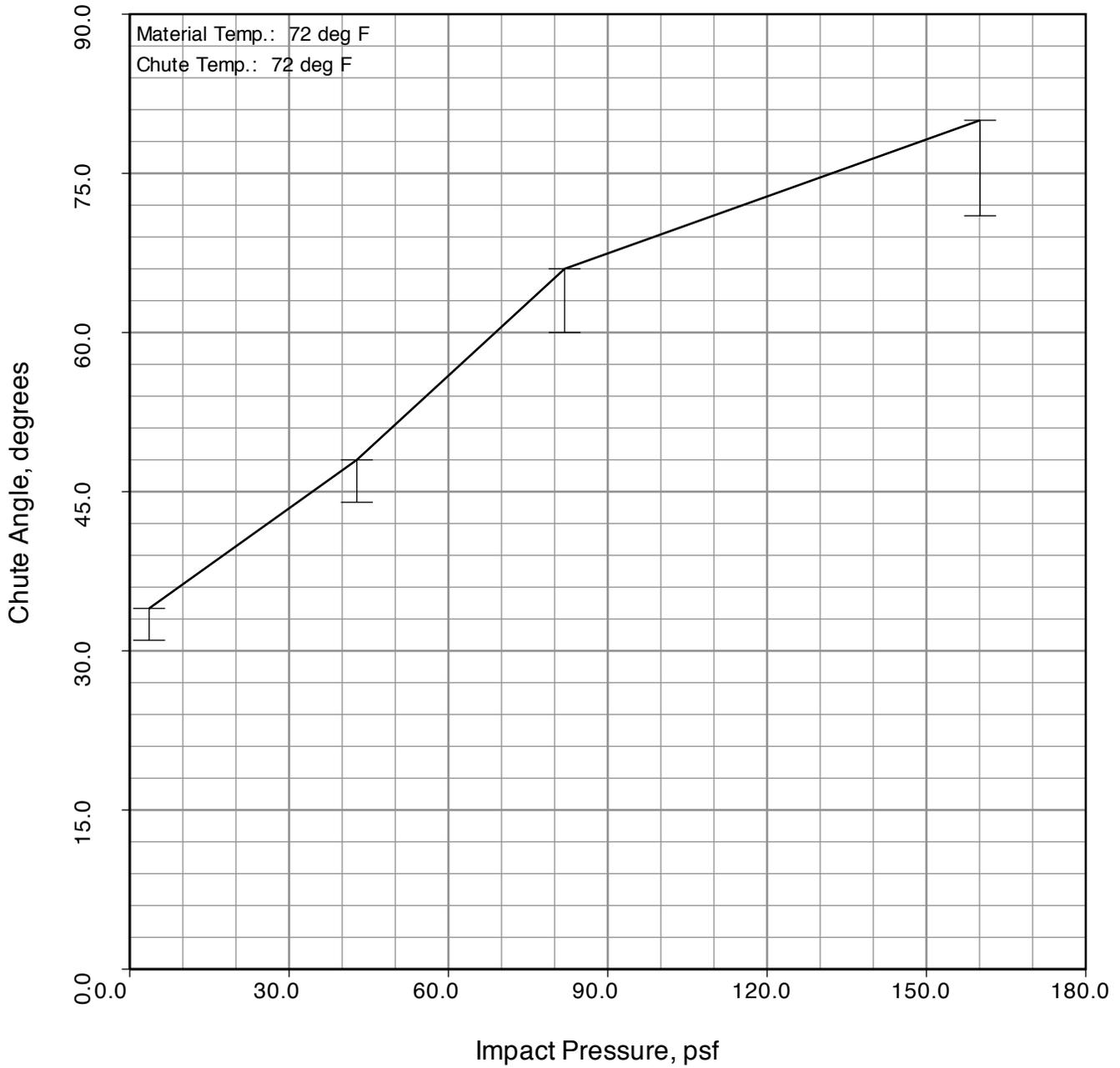
WALL FRICTION ANGLE



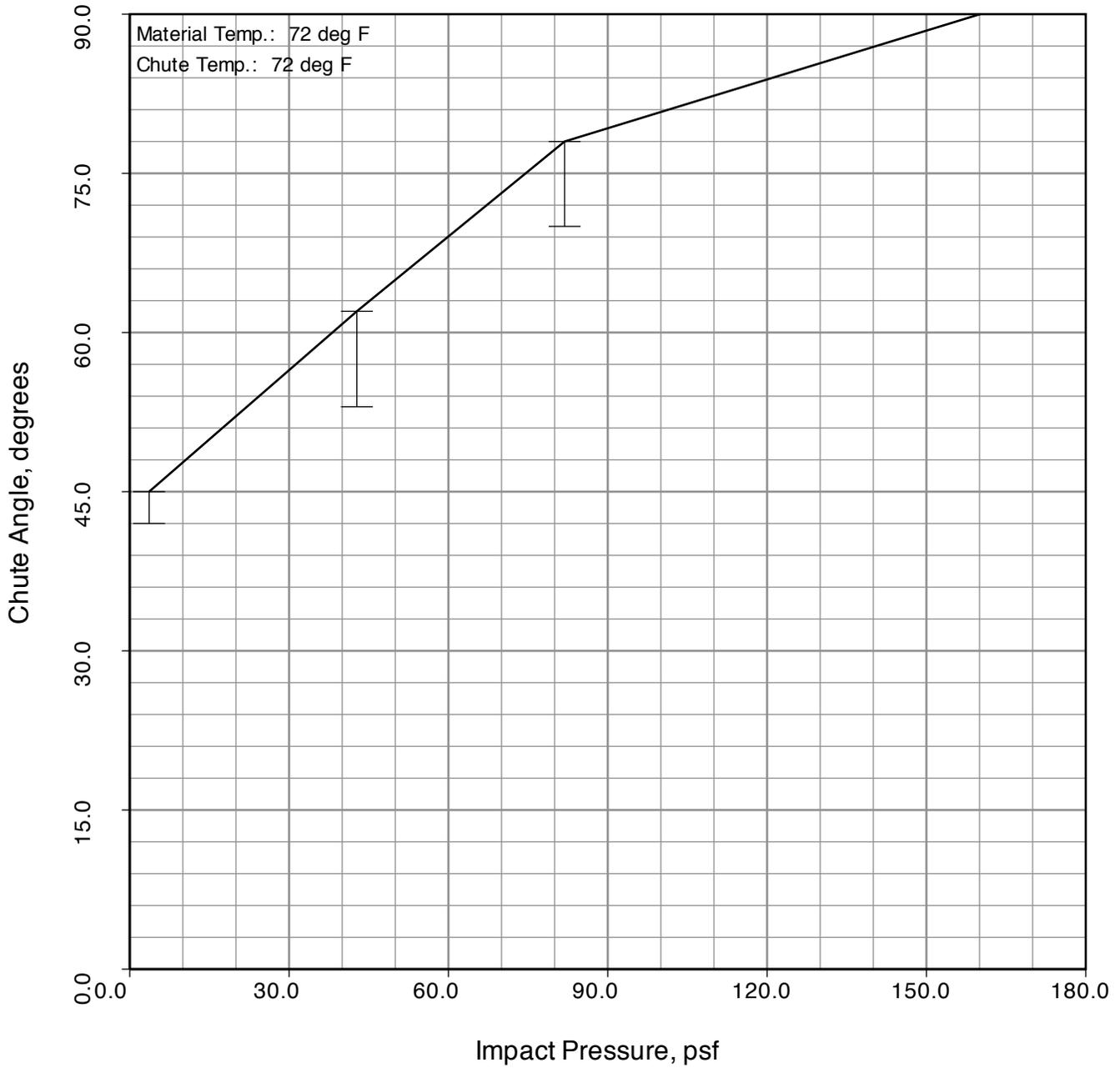
Chute Angles versus Impact Pressure
for 304 #2B Finish Stainless Steel Sheet



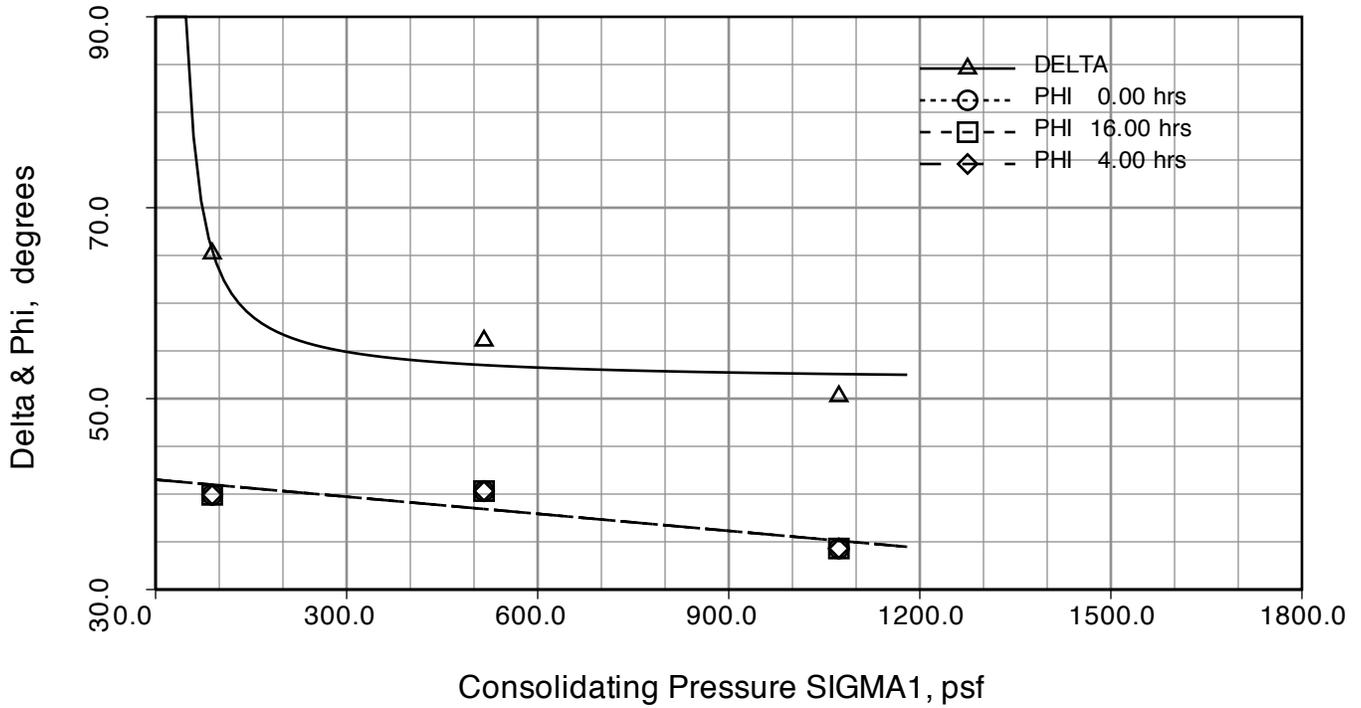
Chute Angles versus Impact Pressure for Tivar 88



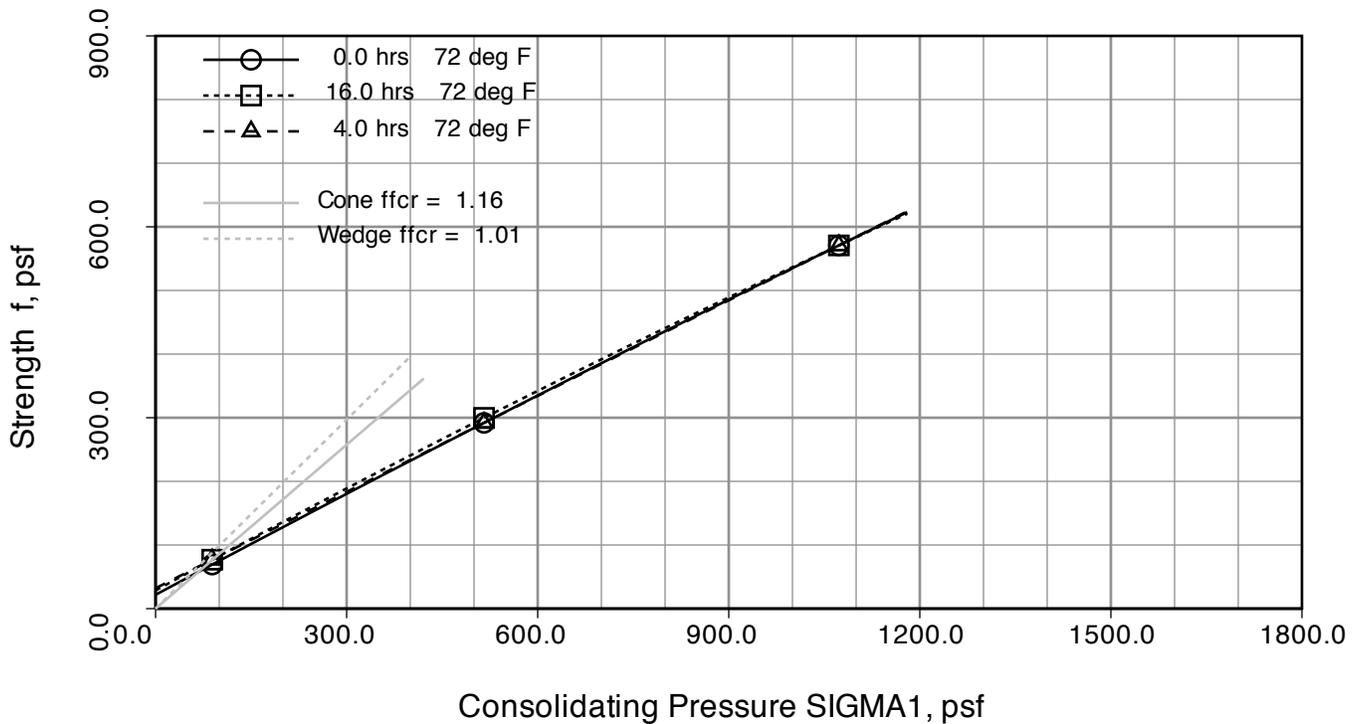
Chute Angles versus Impact Pressure
for Mild Carbon Steel Plate, Mill Finish



DELTA & PHI RELATIONS



FLOW FUNCTION(S)



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

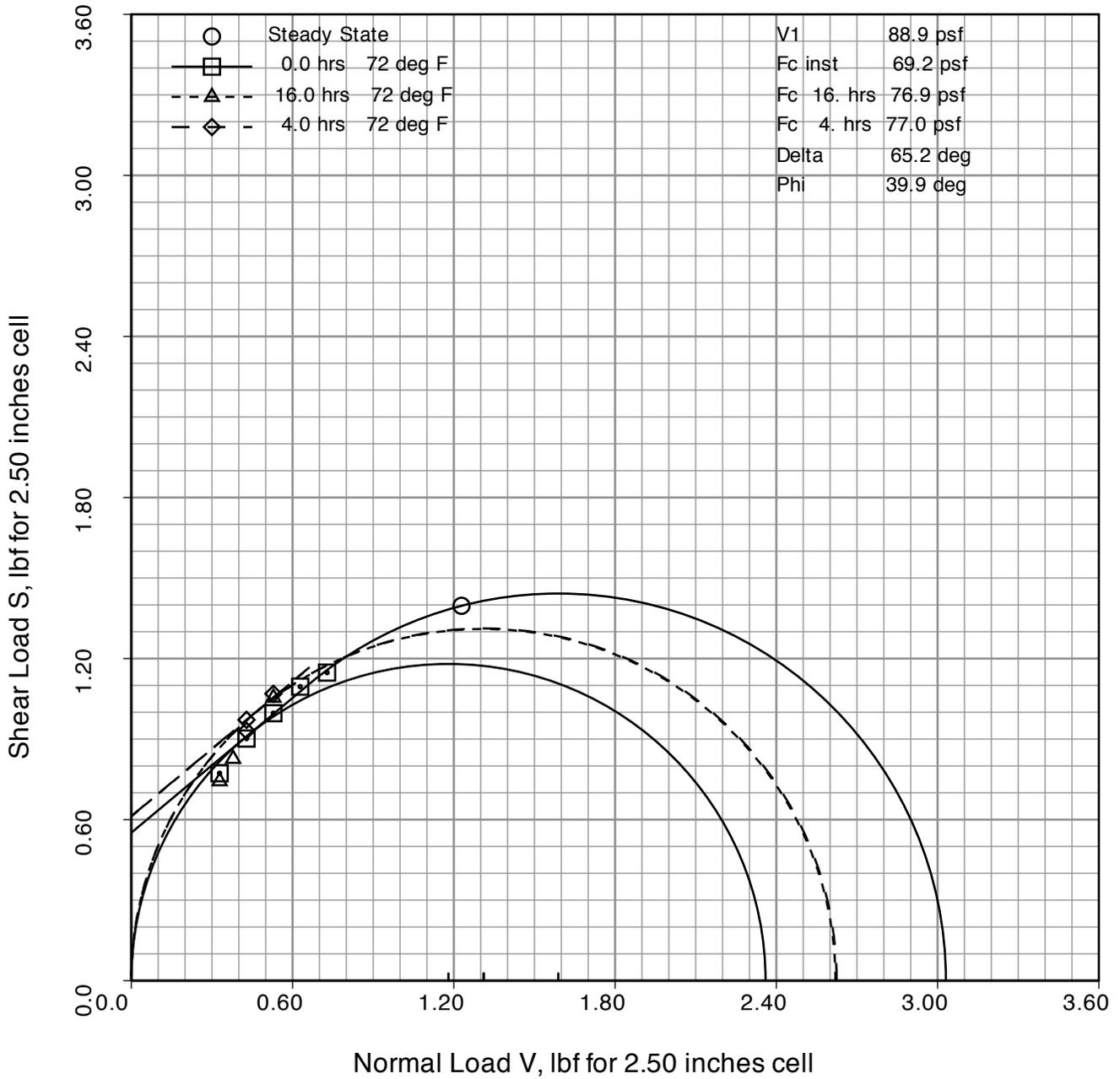
CREATE: 6/03/21

RUN: 6/04/06

JOB#: 10057

ID#: 24540

YIELD LOCUS



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

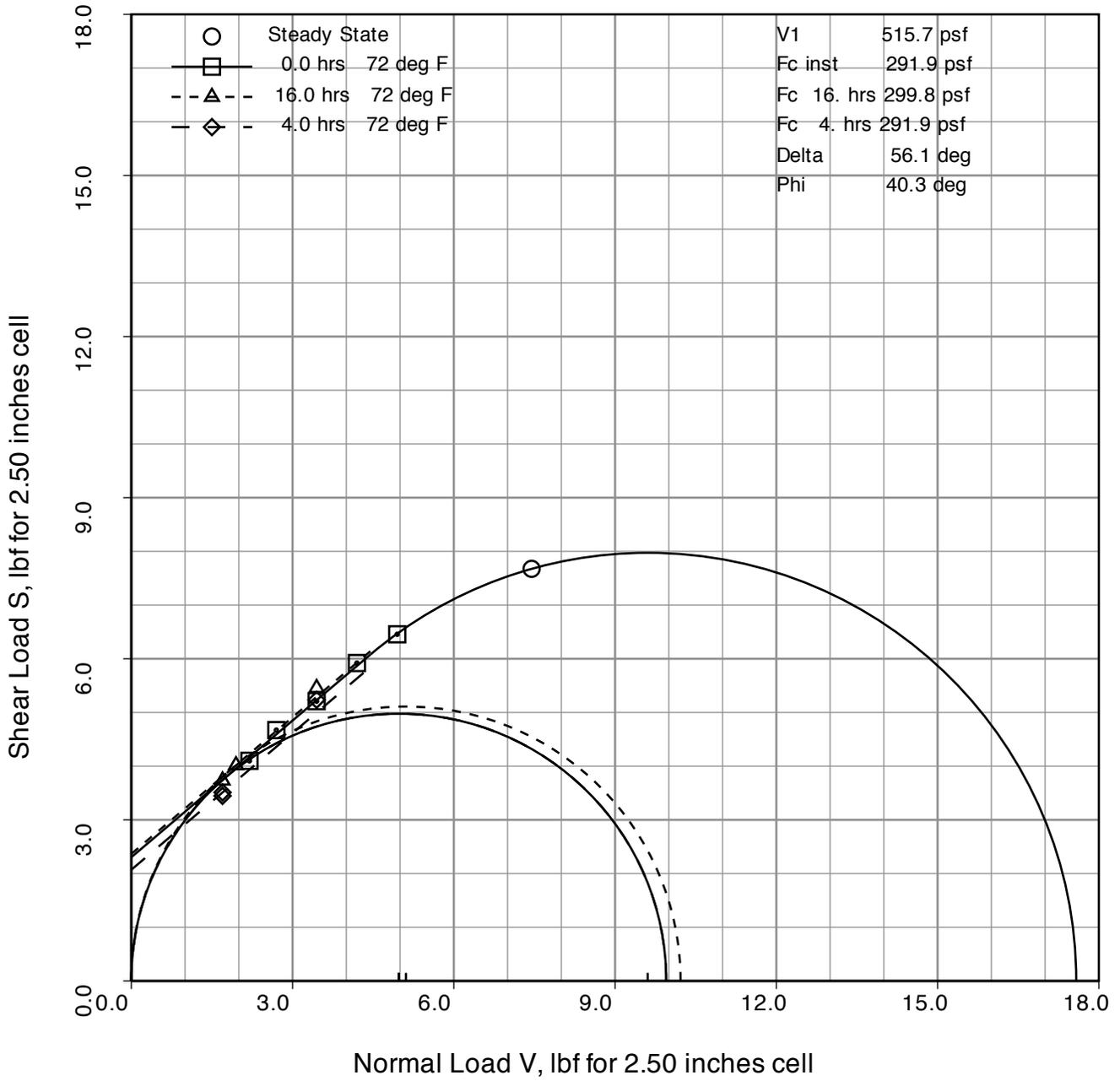
CREATE: 6/03/21

RUN: 6/04/06

JOB#: 10057

ID#: 24540

YIELD LOCUS



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

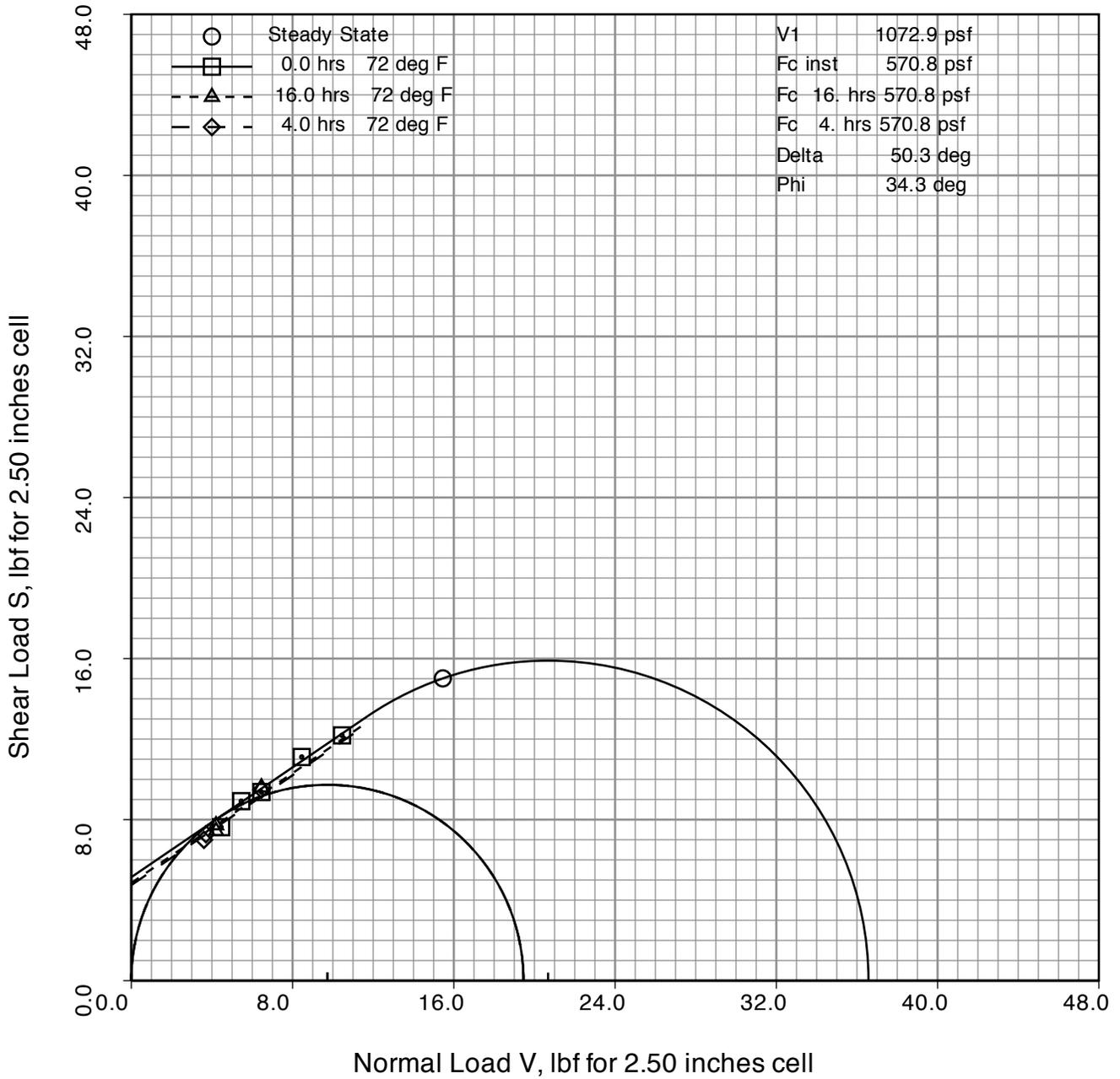
CREATE: 6/03/21

RUN: 6/04/06

JOB#: 10057

ID#: 24540

YIELD LOCUS



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

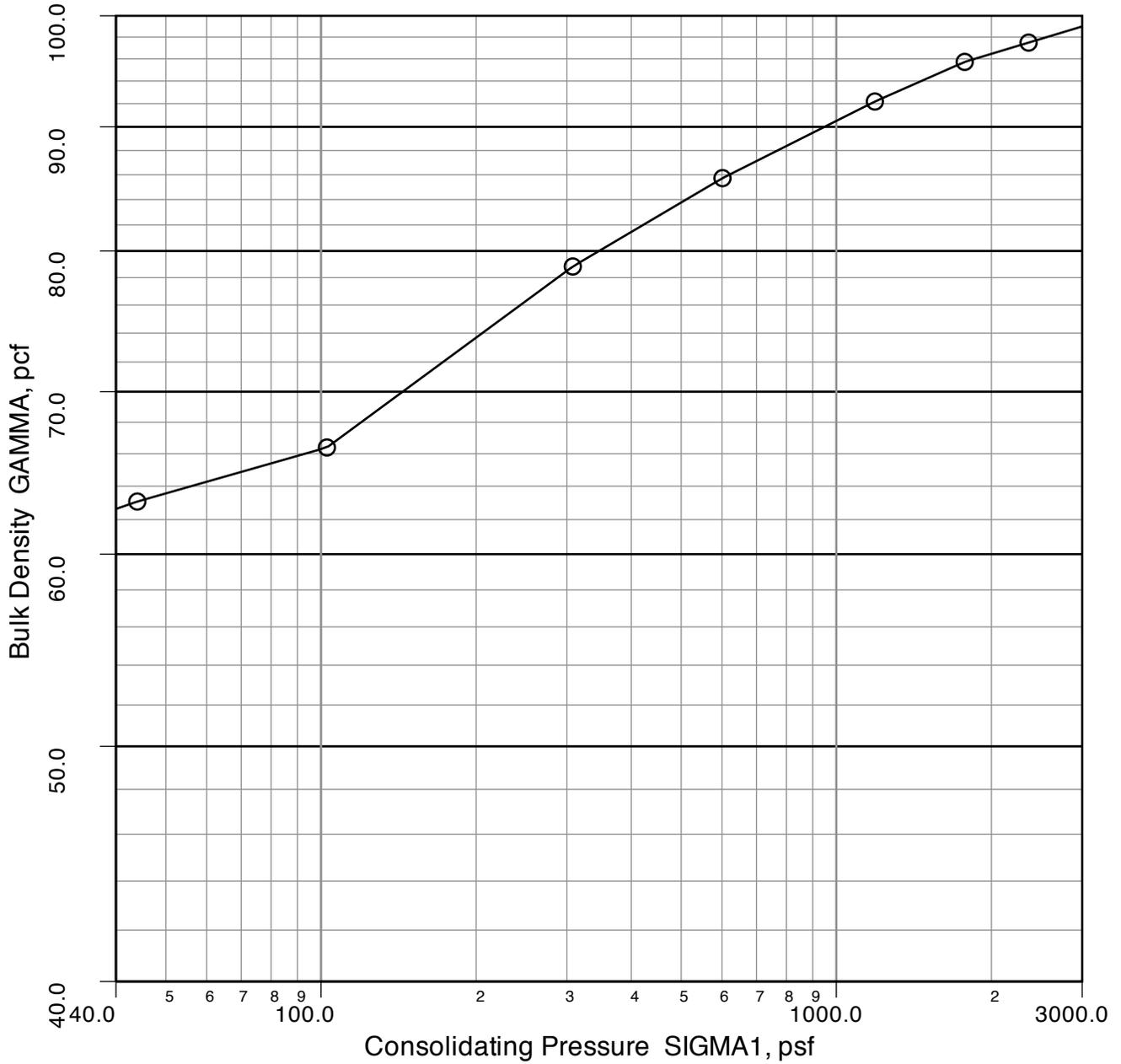
CREATE: 6/03/21

RUN: 6/04/06

JOB#: 10057

ID#: 24540

BULK DENSITY VS. CONSOLIDATING PRESSURE



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

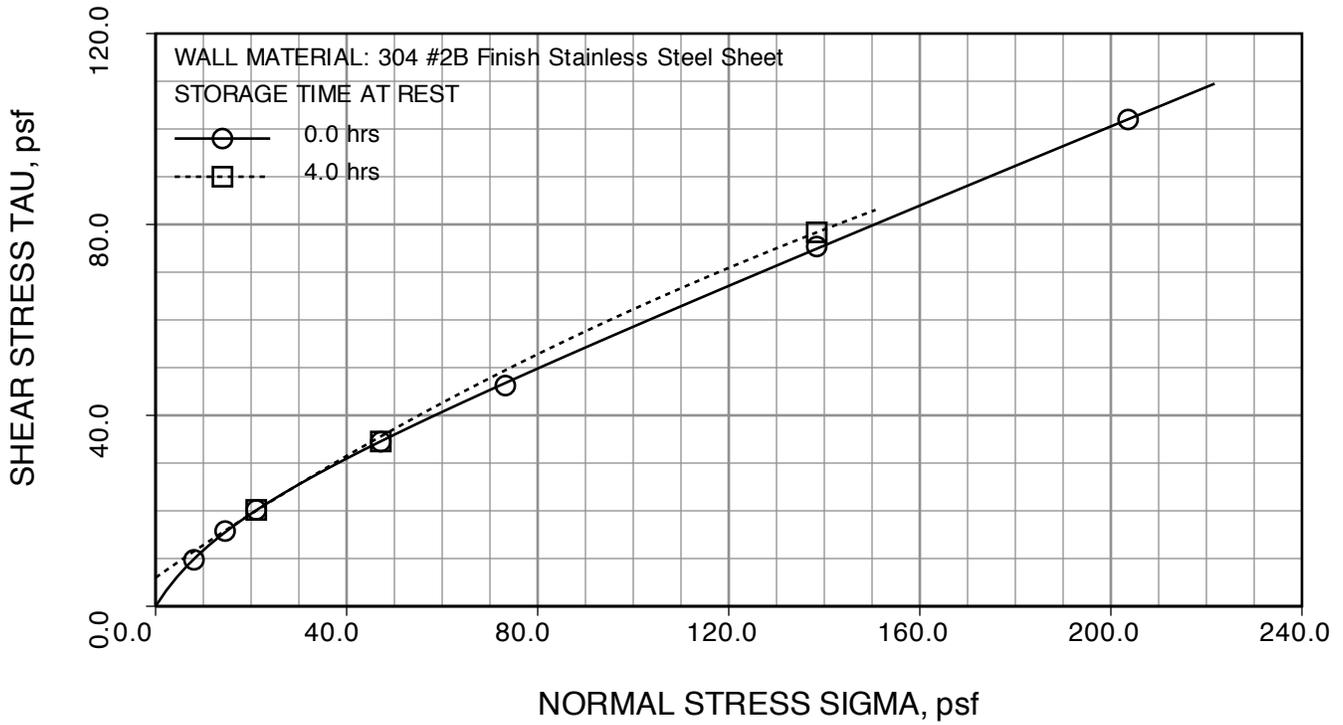
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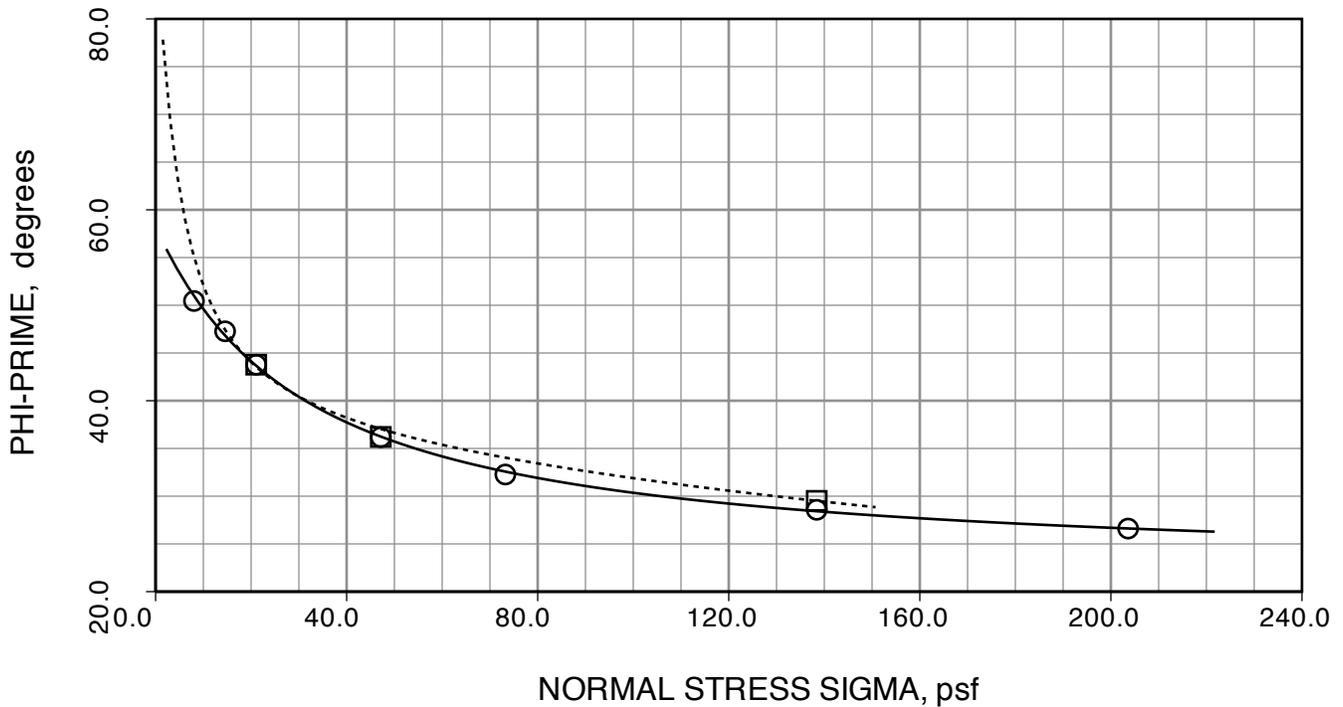
RUN: 6/04/06

ID#: 24540

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

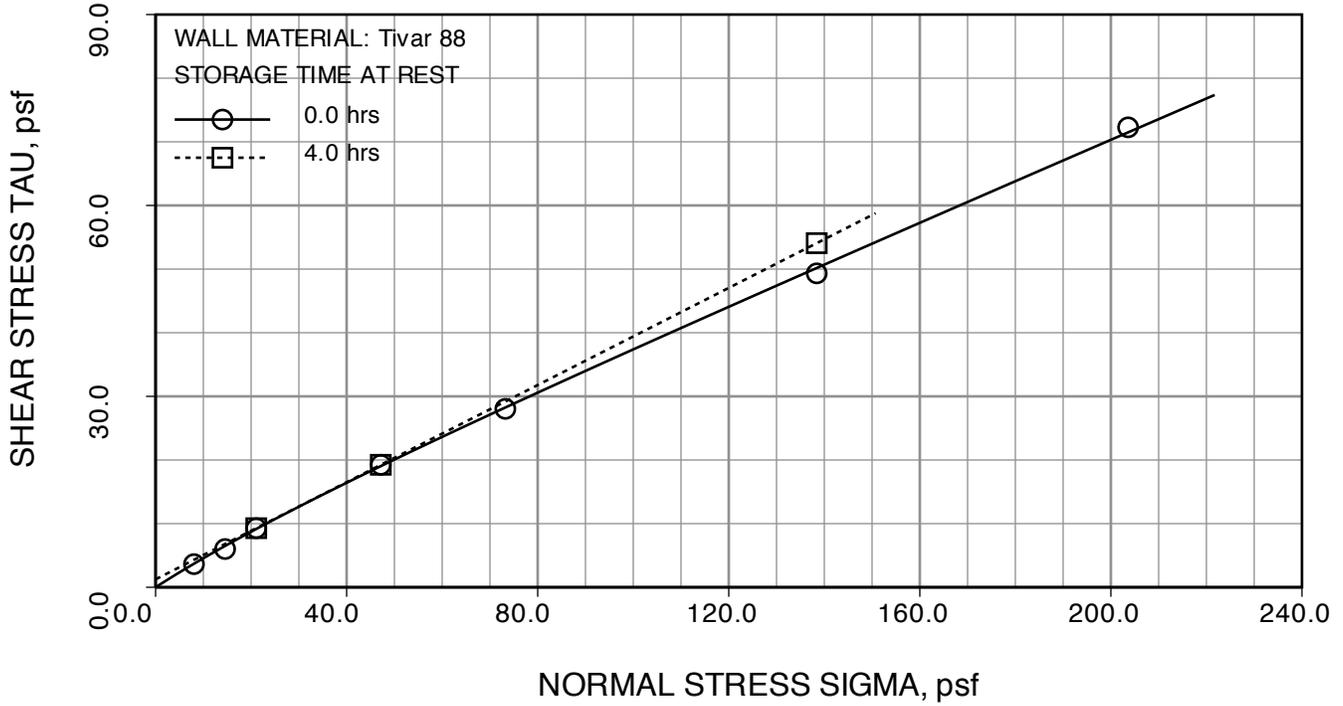
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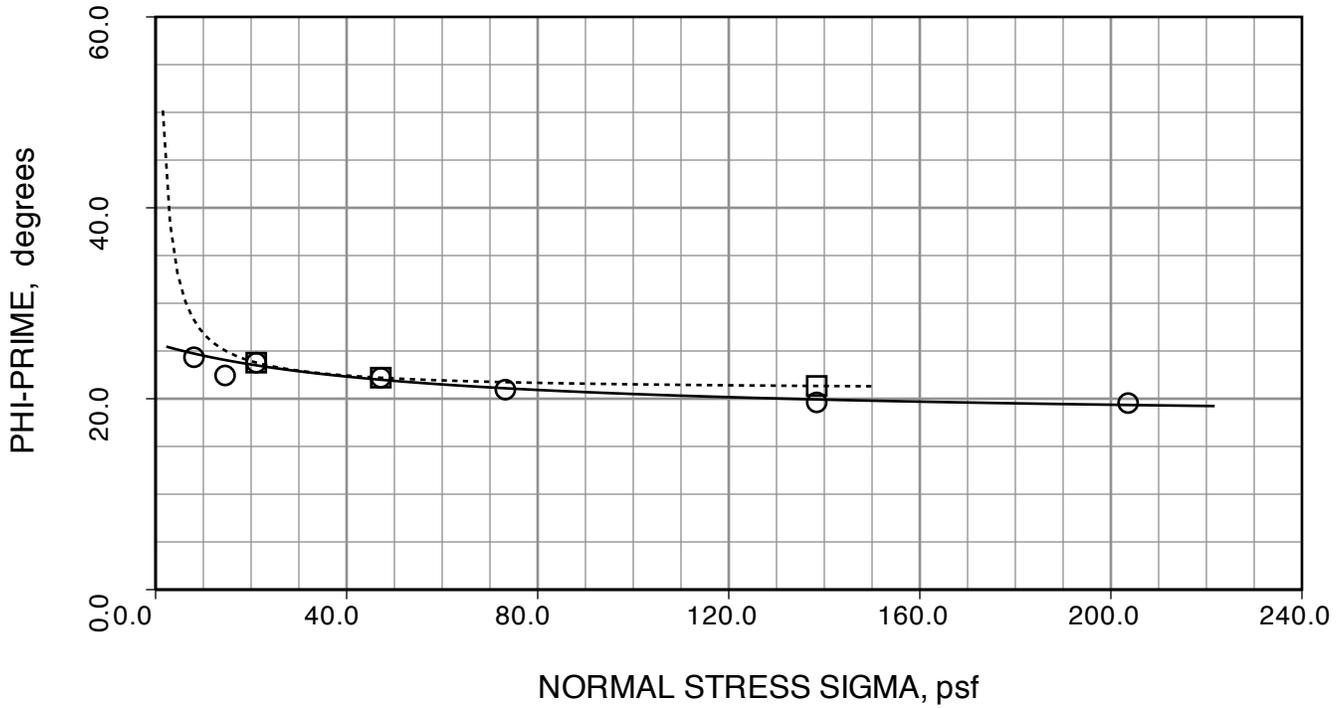
RUN: 6/04/06

ID#: 24540

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

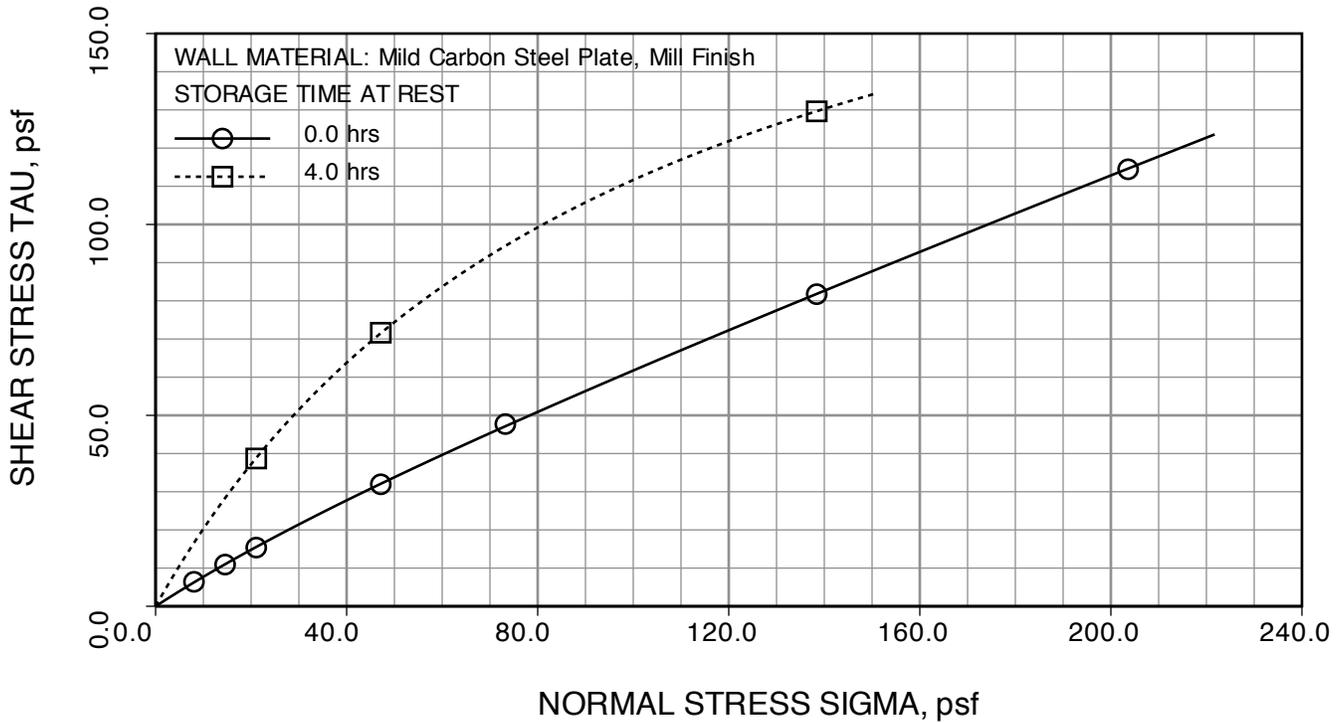
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JOB#: 10057

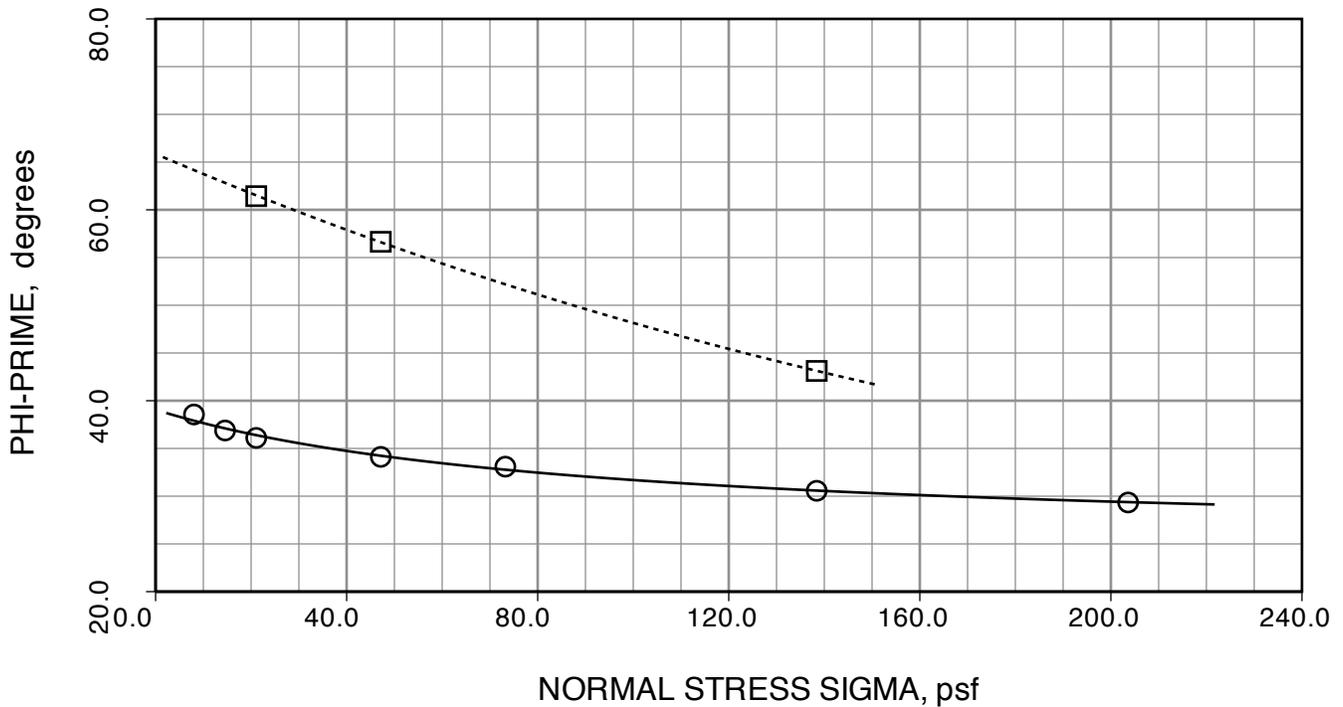
RUN: 6/04/06

ID#: 24540

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

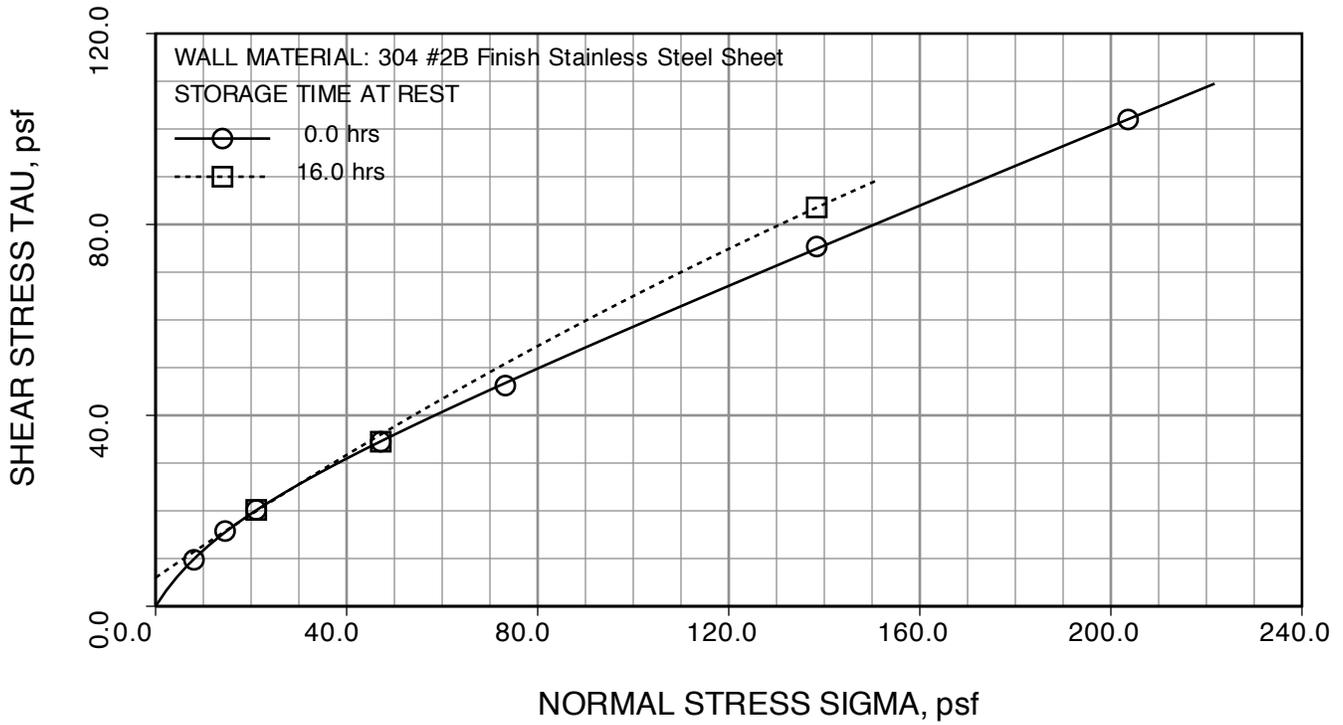
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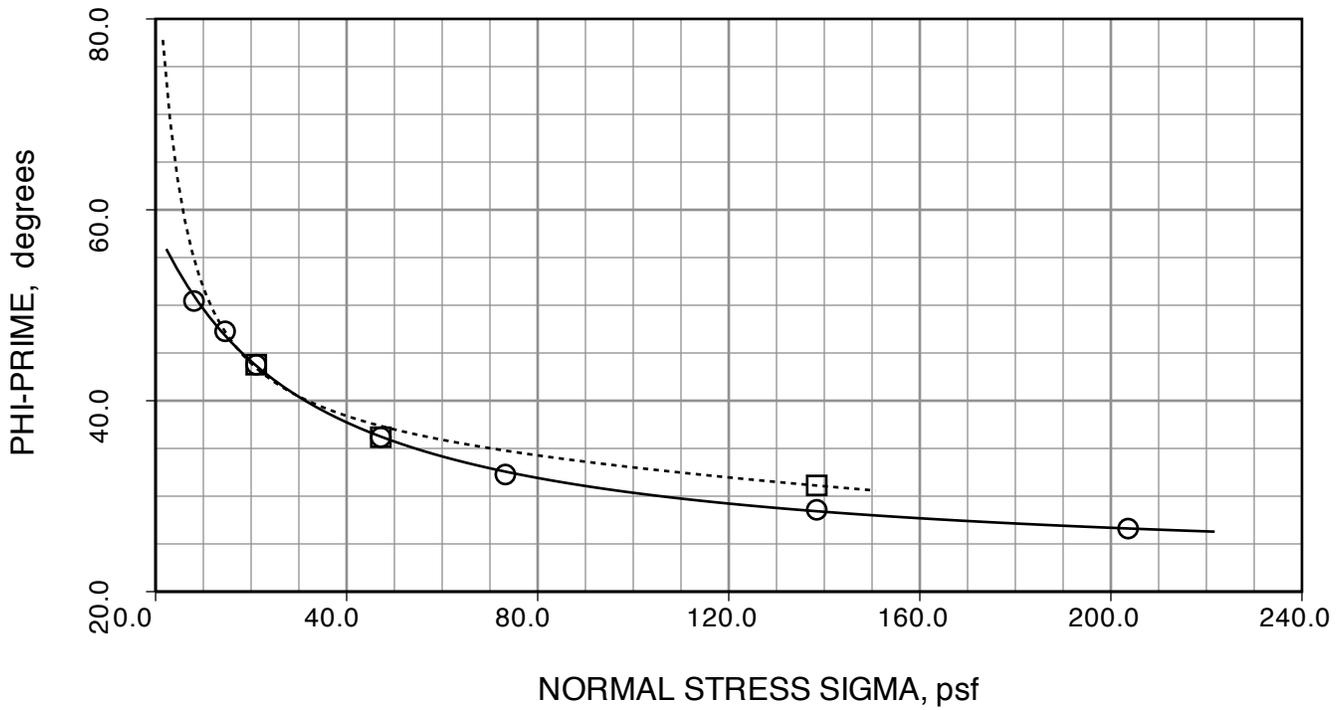
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ID#: 24540

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

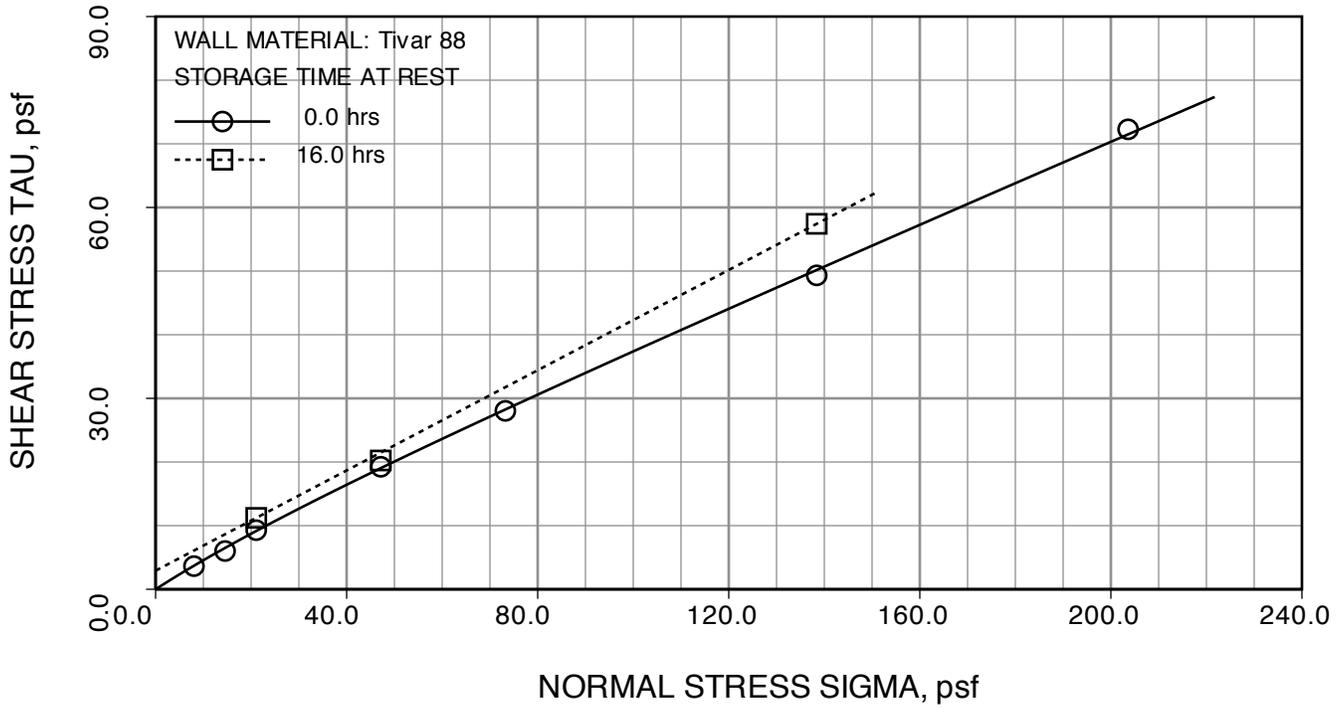
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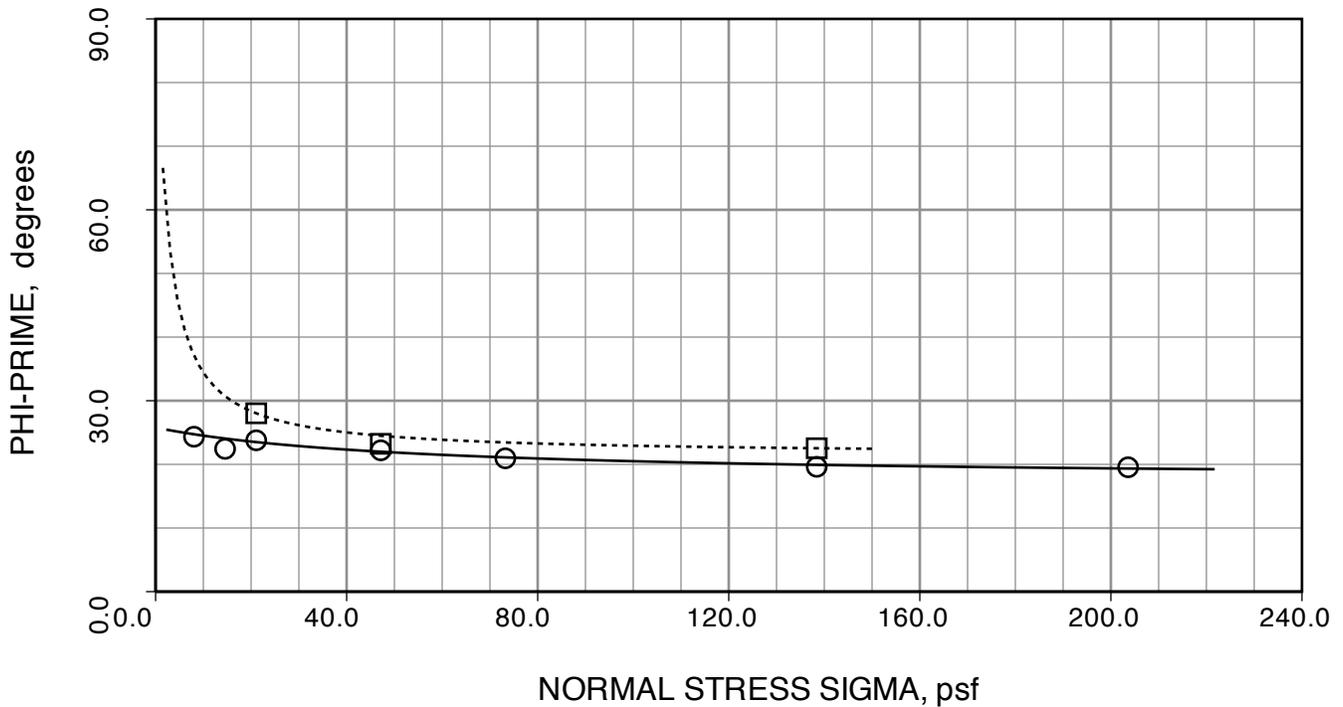
RUN: 6/04/06

ID#: 24540

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

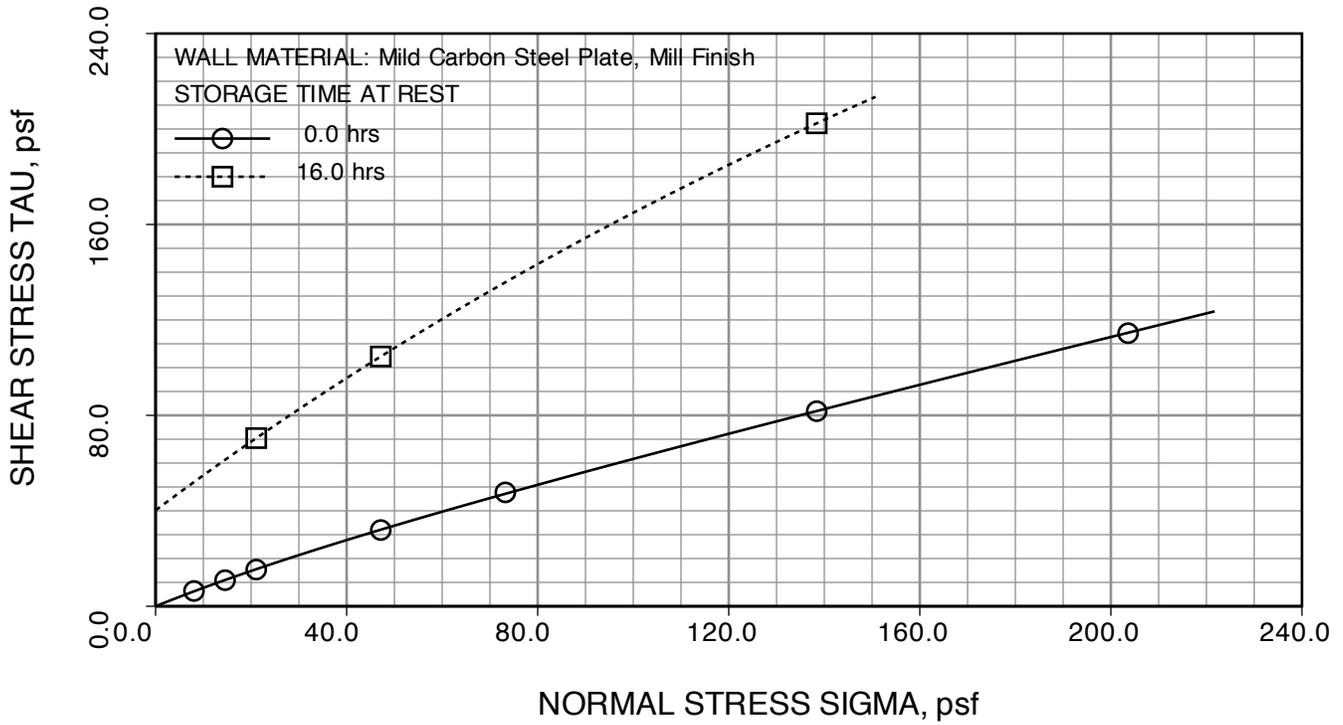
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JOB#: 10057

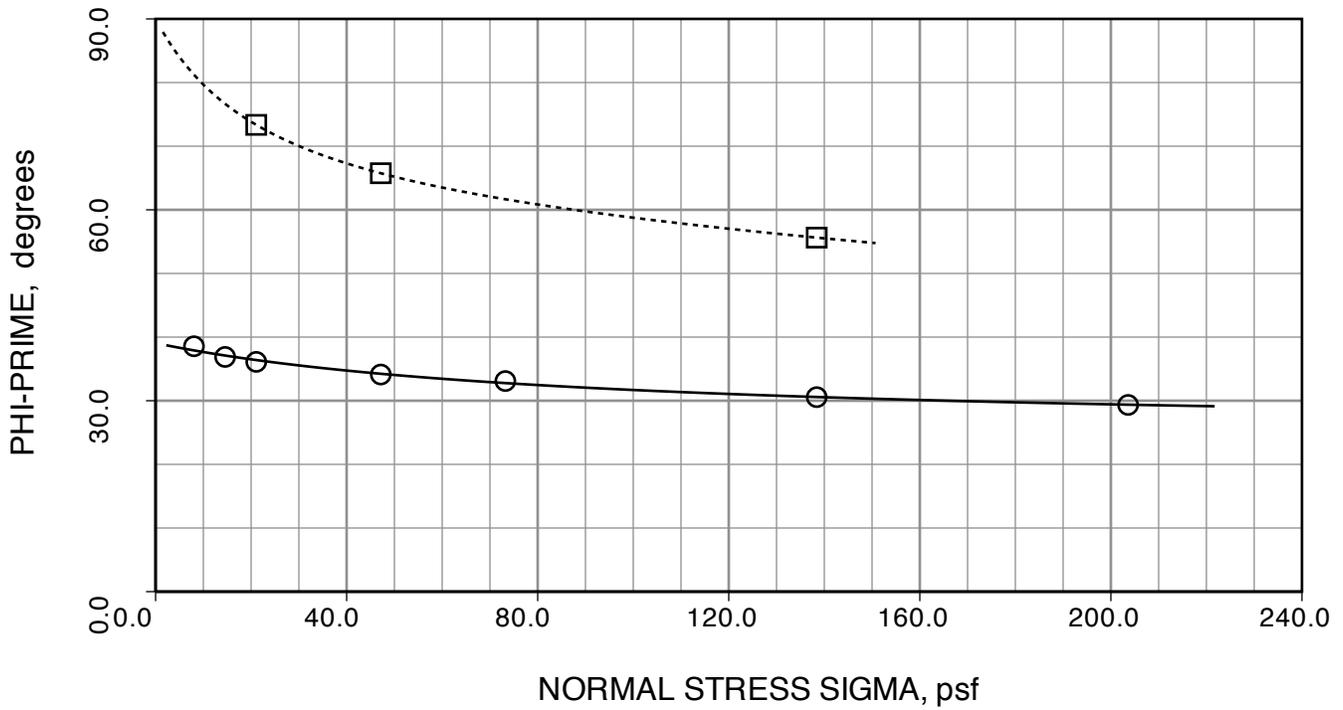
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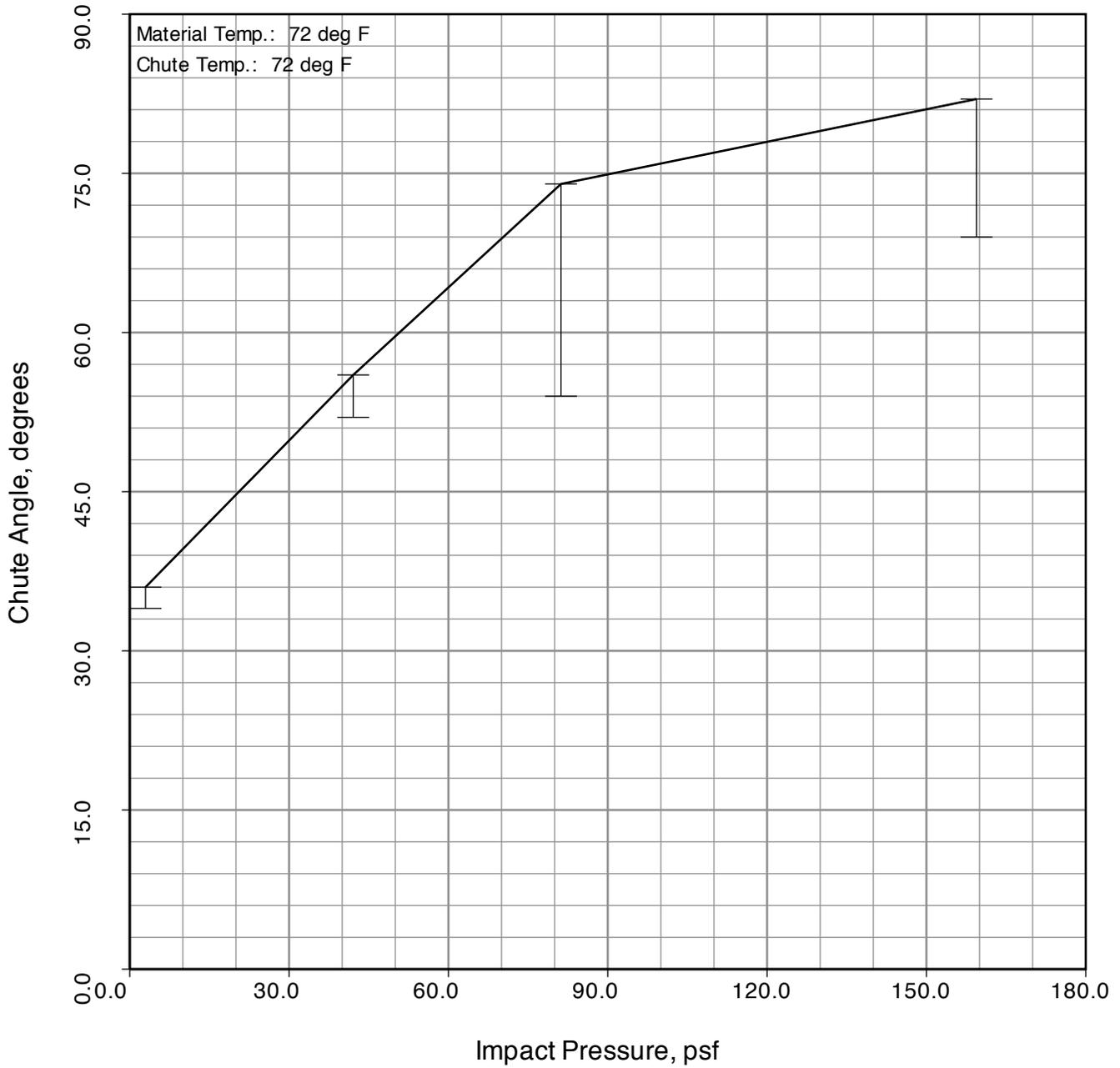
WALL YIELD LOCUS



WALL FRICTION ANGLE



Chute Angles versus Impact Pressure
for 304 #2B Finish Stainless Steel Sheet



BULK MATERIAL: Slime Tailings GABT-8

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

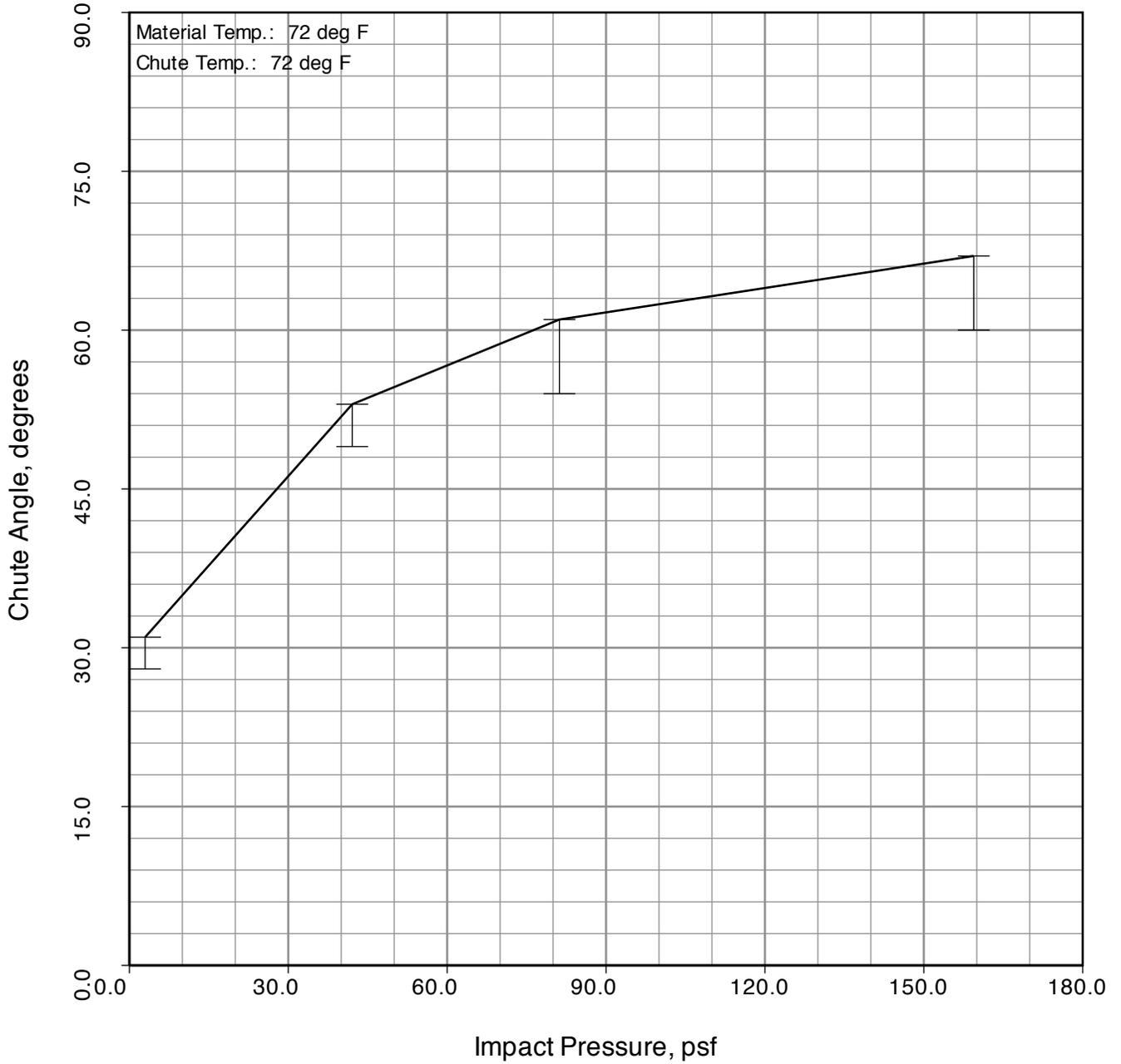
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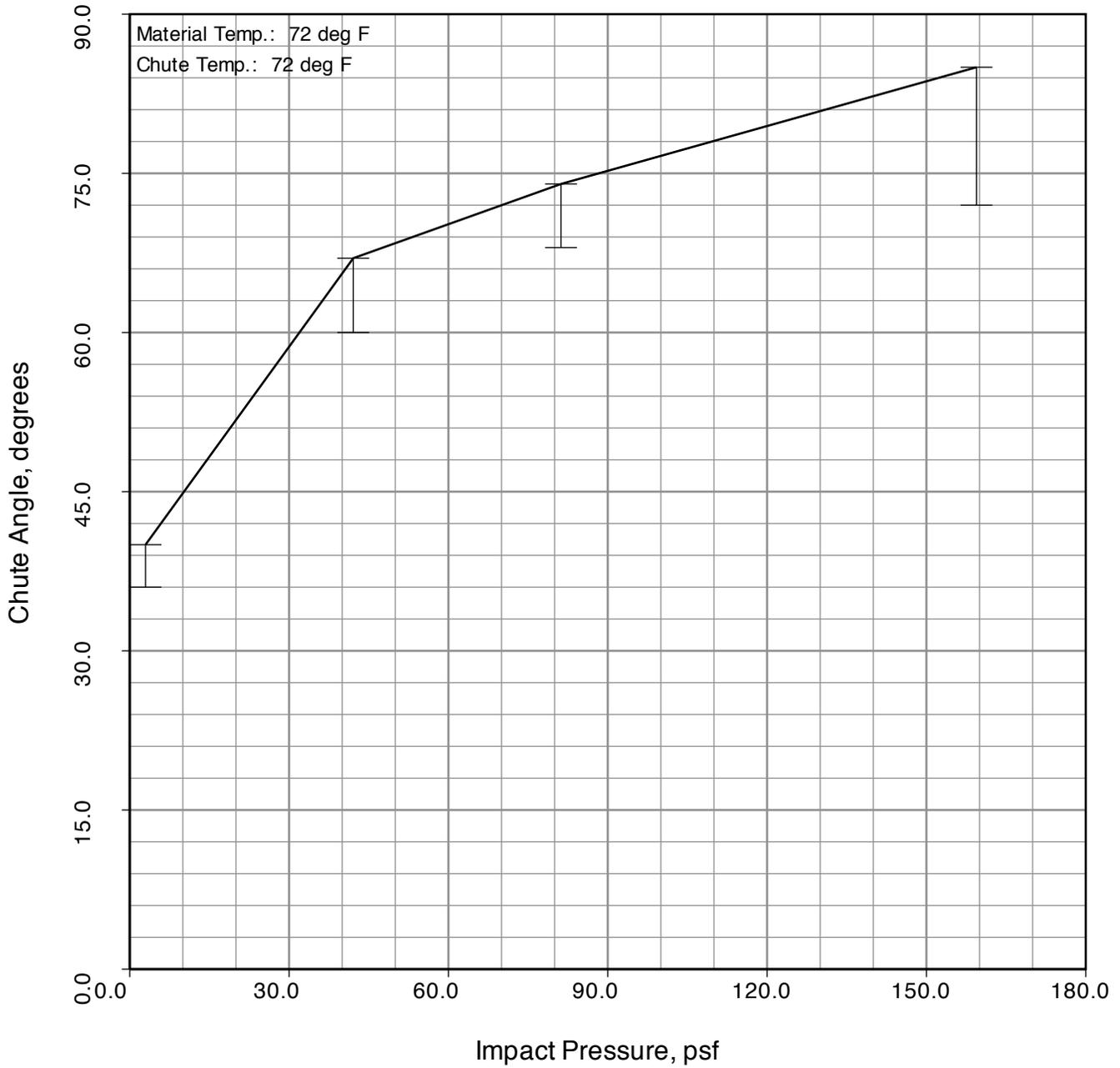
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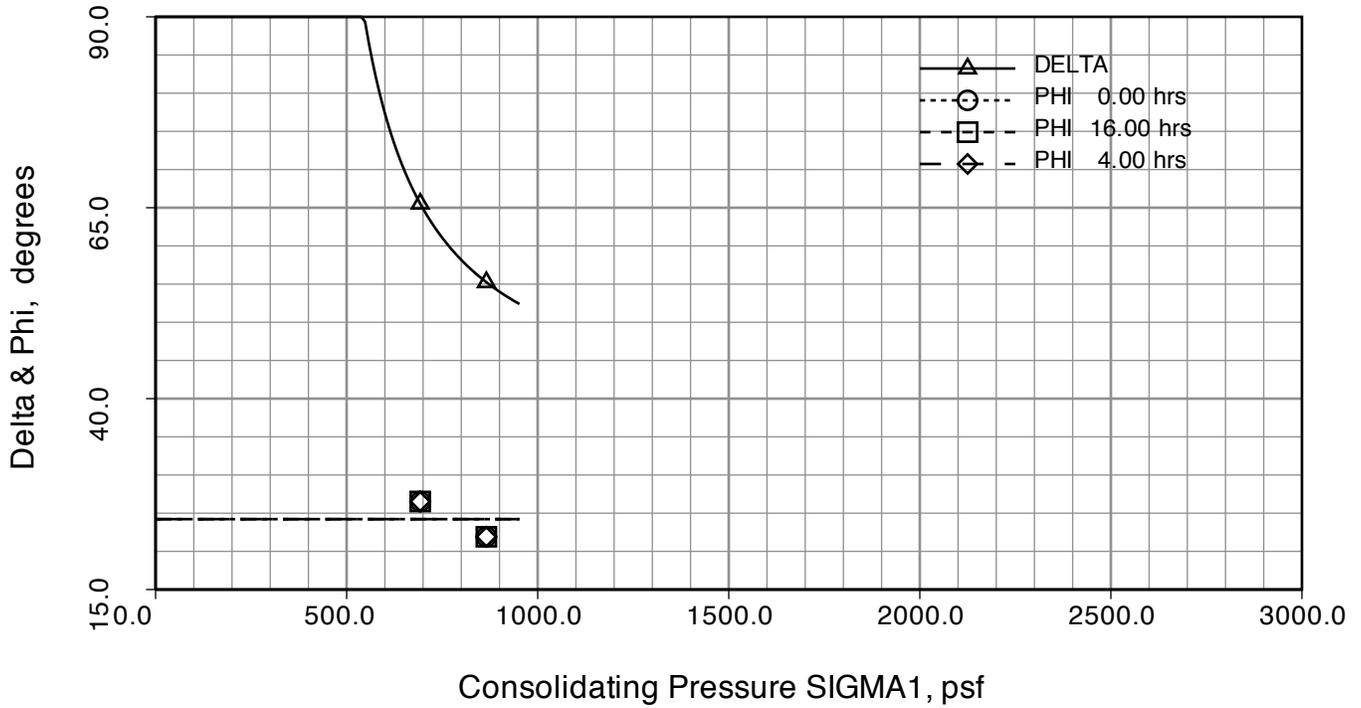
Chute Angles versus Impact Pressure for Tivar 88



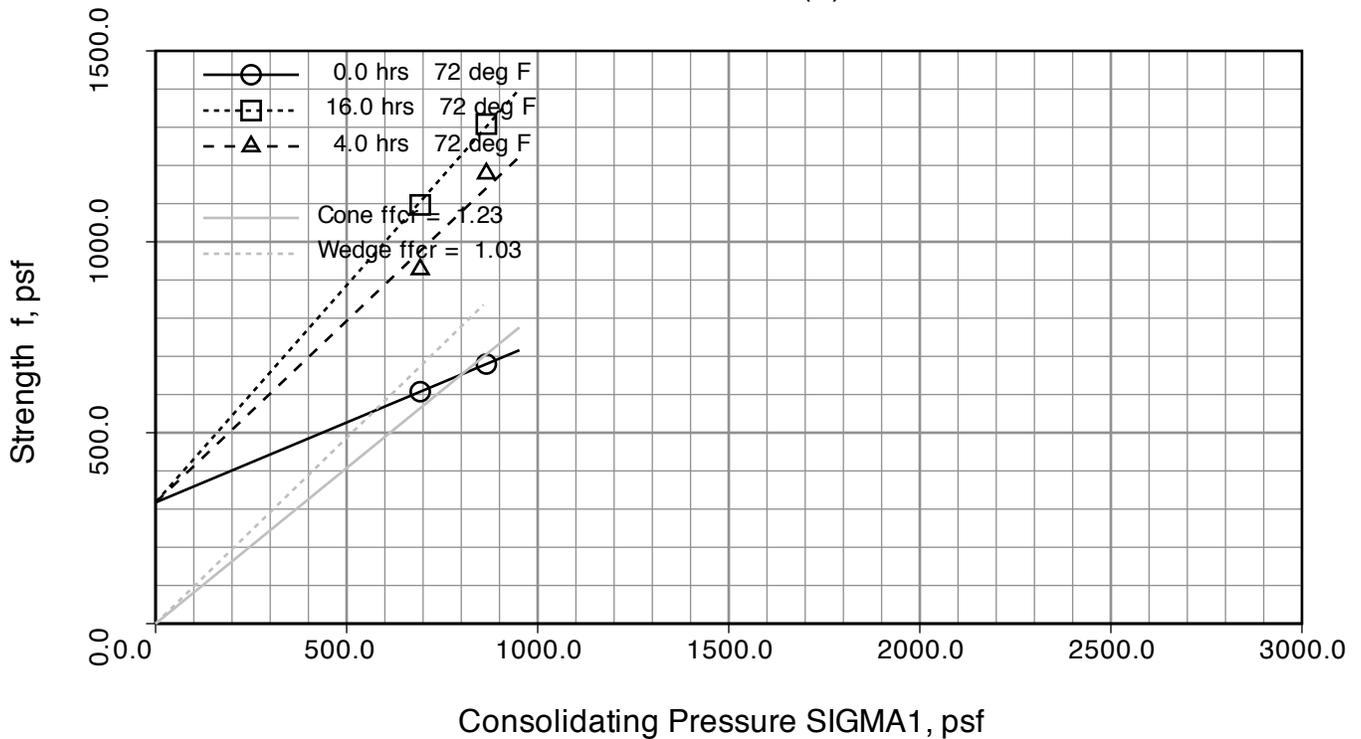
Chute Angles versus Impact Pressure
for Mild Carbon Steel Plate, Mill Finish



DELTA & PHI RELATIONS



FLOW FUNCTION(S)



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

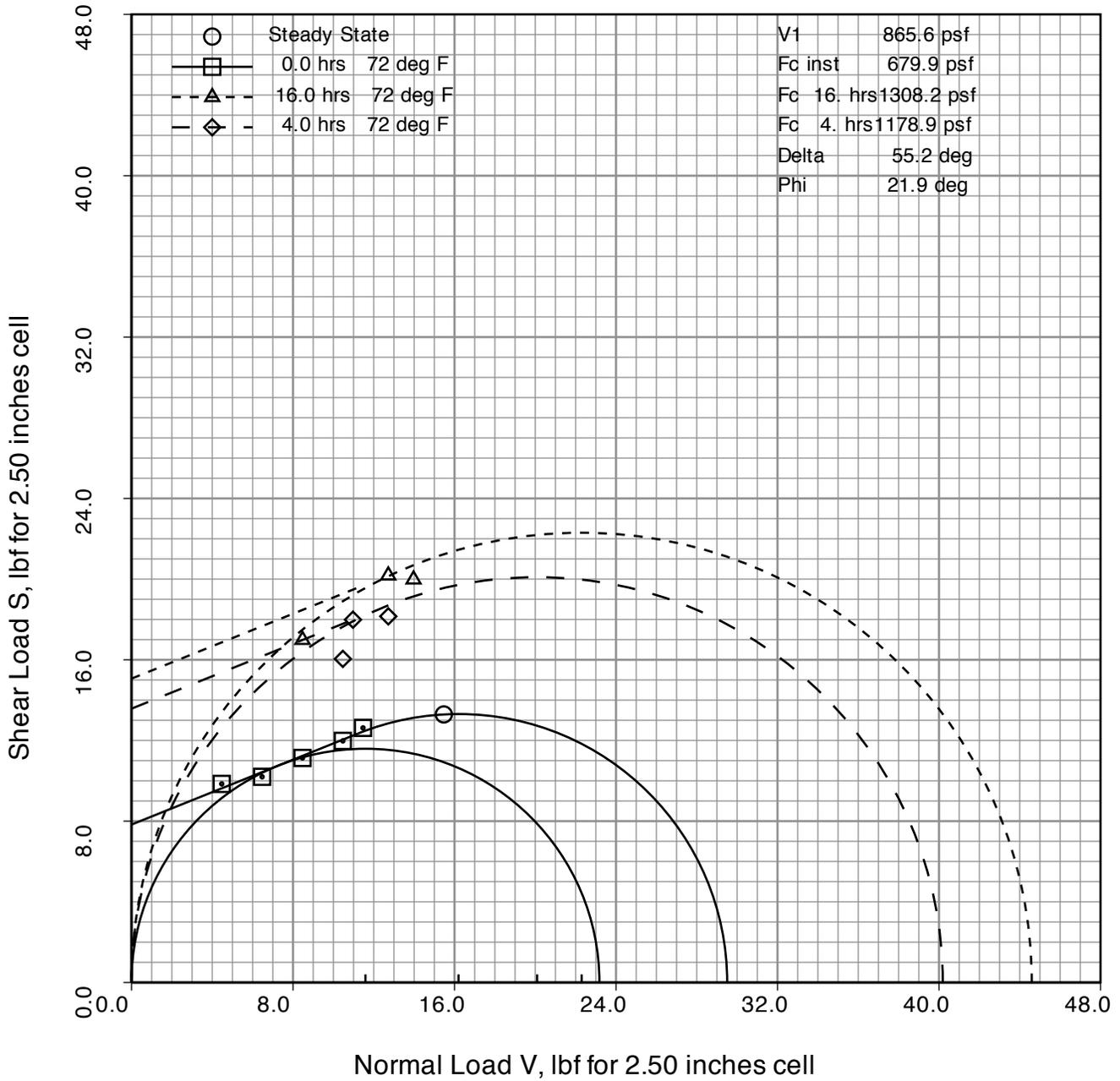
CREATE: 6/03/22

RUN: 6/04/06

JOB#: 10057

ID#: 24541

YIELD LOCUS



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

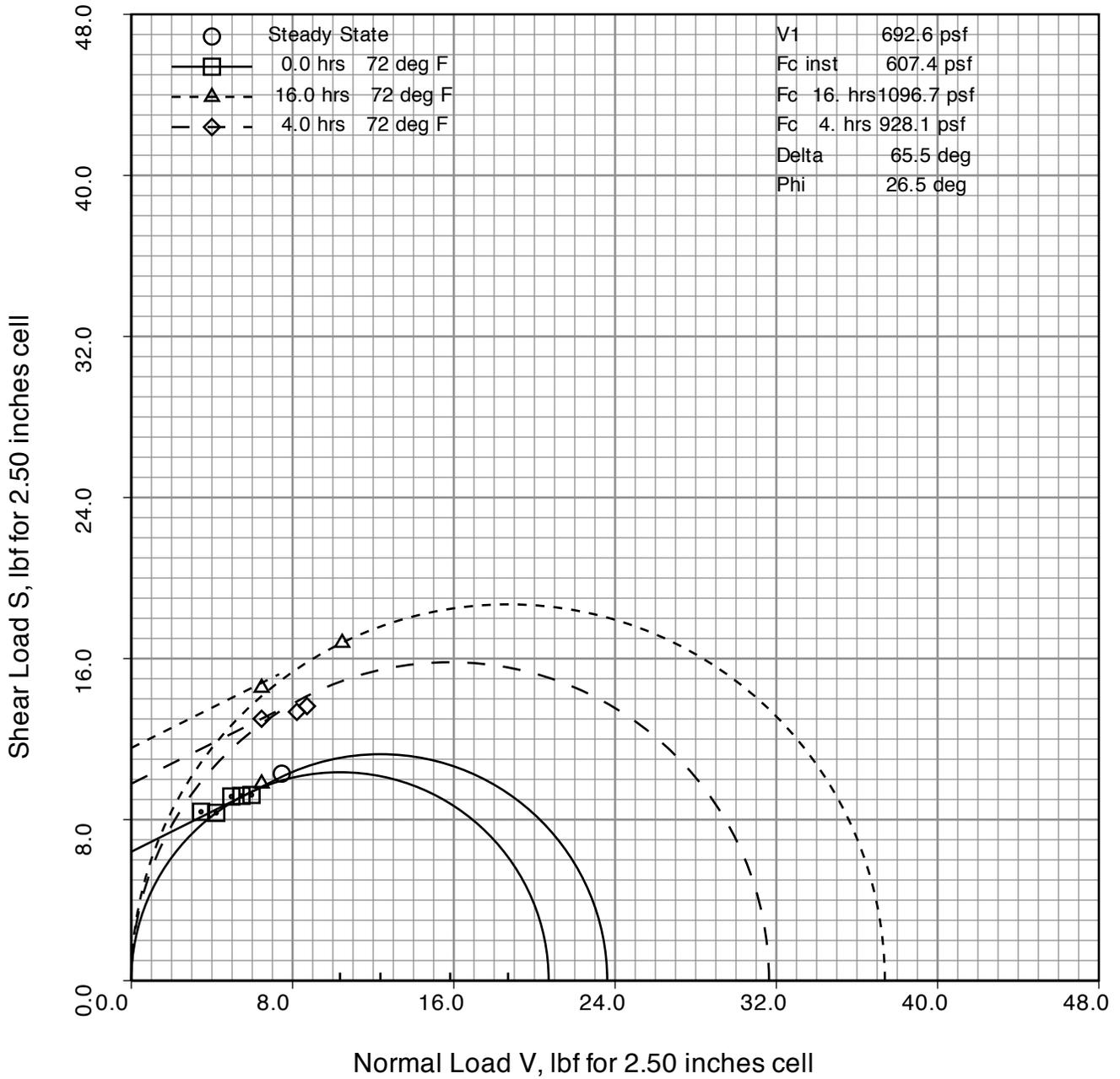
CREATE: 6/03/22

RUN: 6/04/06

JOB#: 10057

ID#: 24541

YIELD LOCUS



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

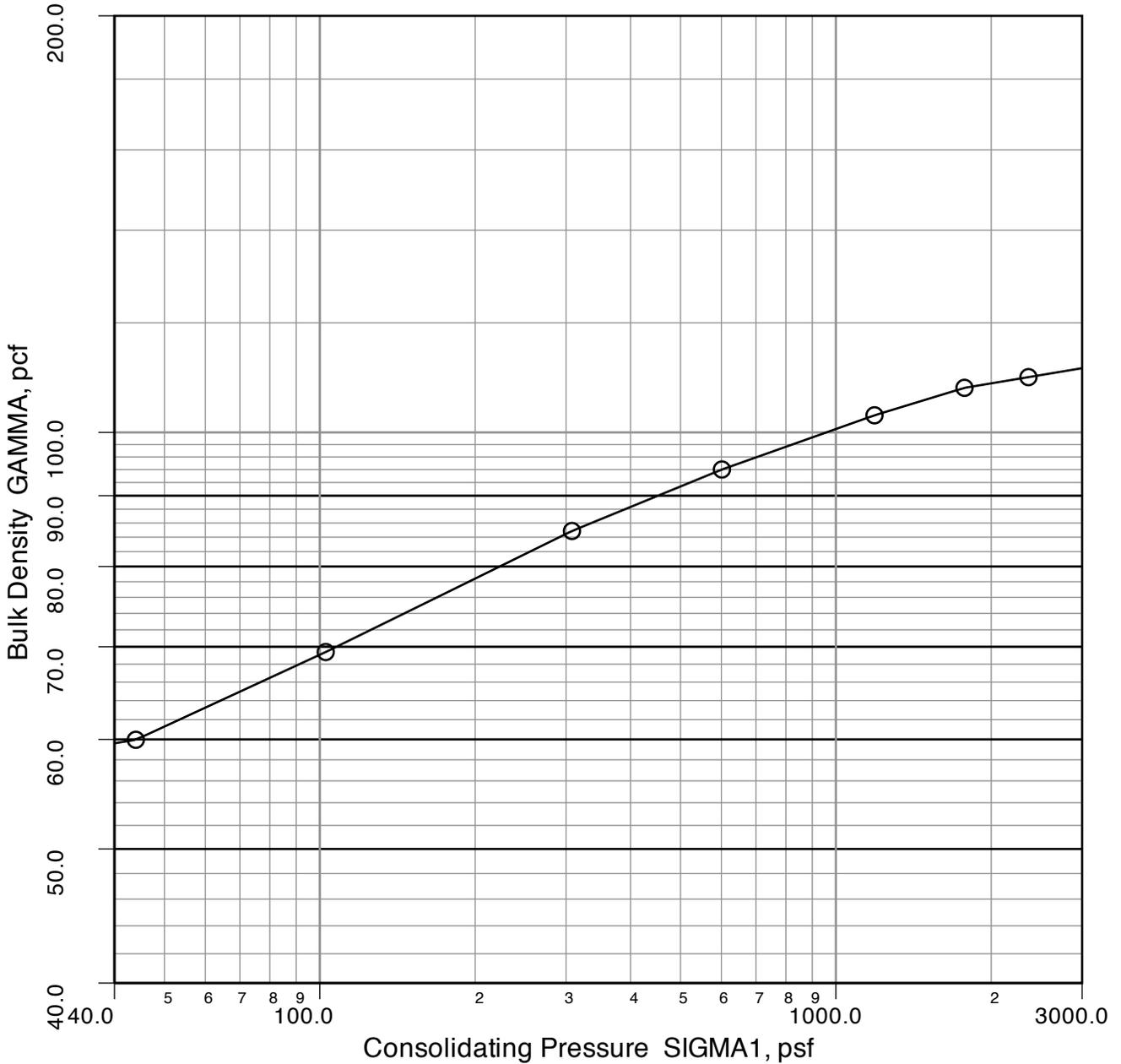
CREATE: 6/03/22

RUN: 6/04/06

JOB#: 10057

ID#: 24541

BULK DENSITY VS. CONSOLIDATING PRESSURE



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

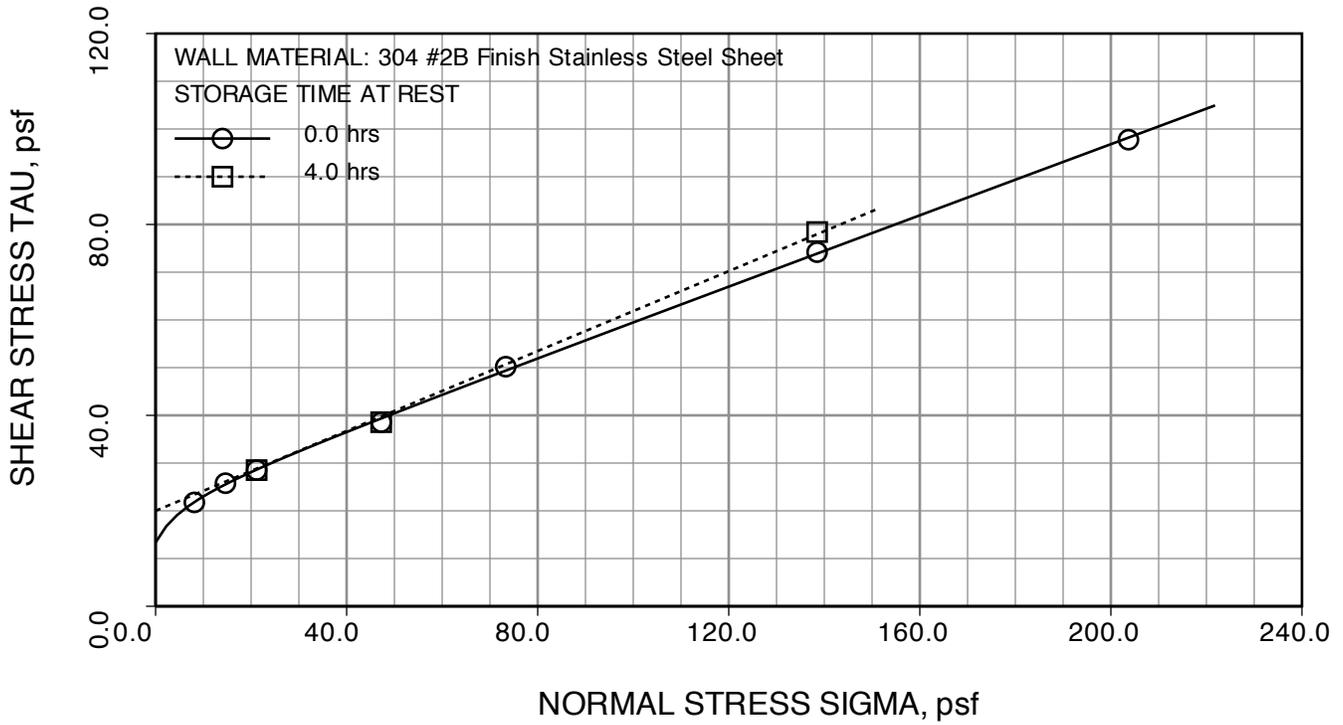
CREATE: 6/03/22

JOB#: 10057

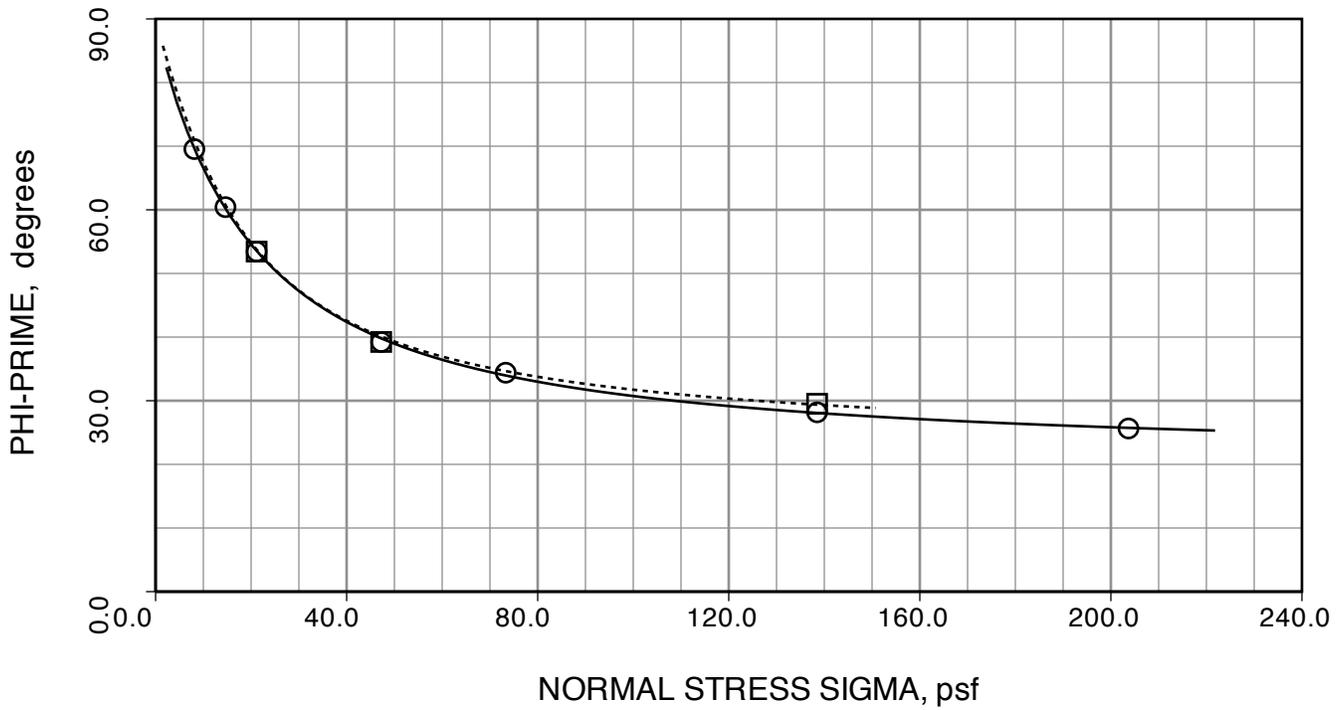
RUN: 6/04/06

ID#: 24541

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

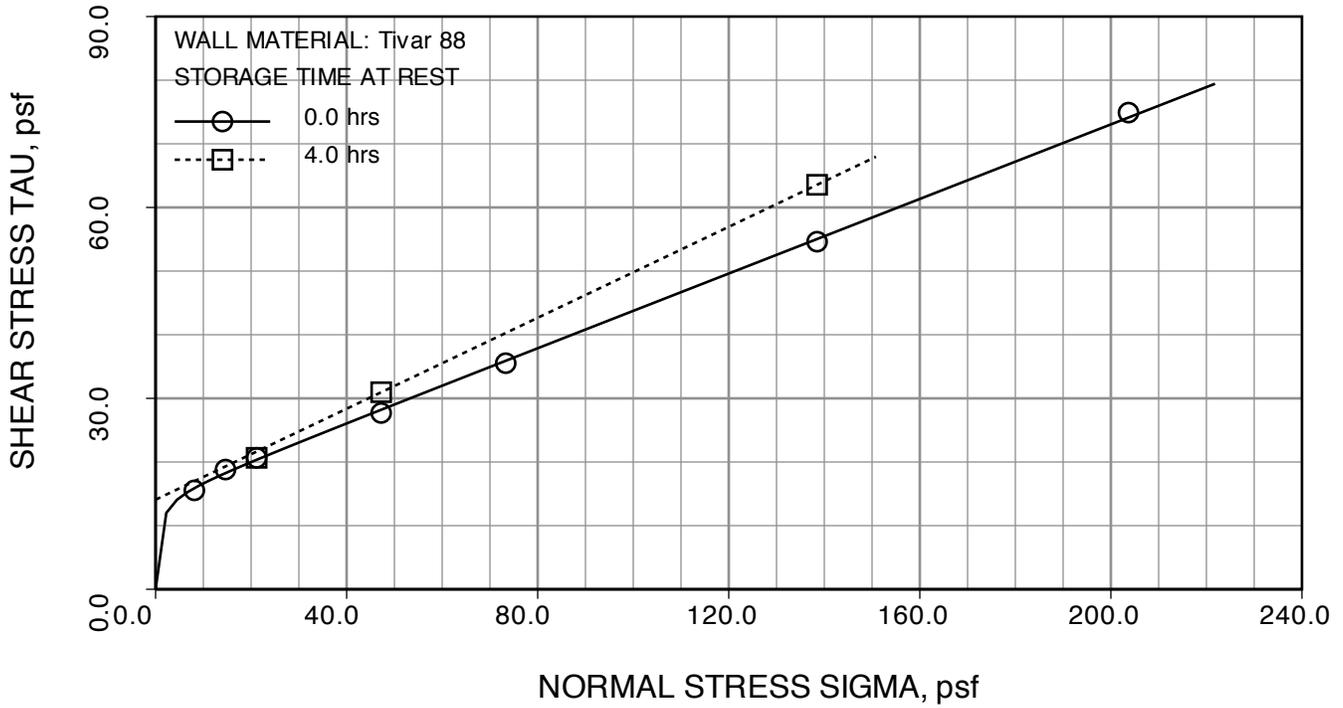
CREATE: 6/03/22

JOB#: 10057

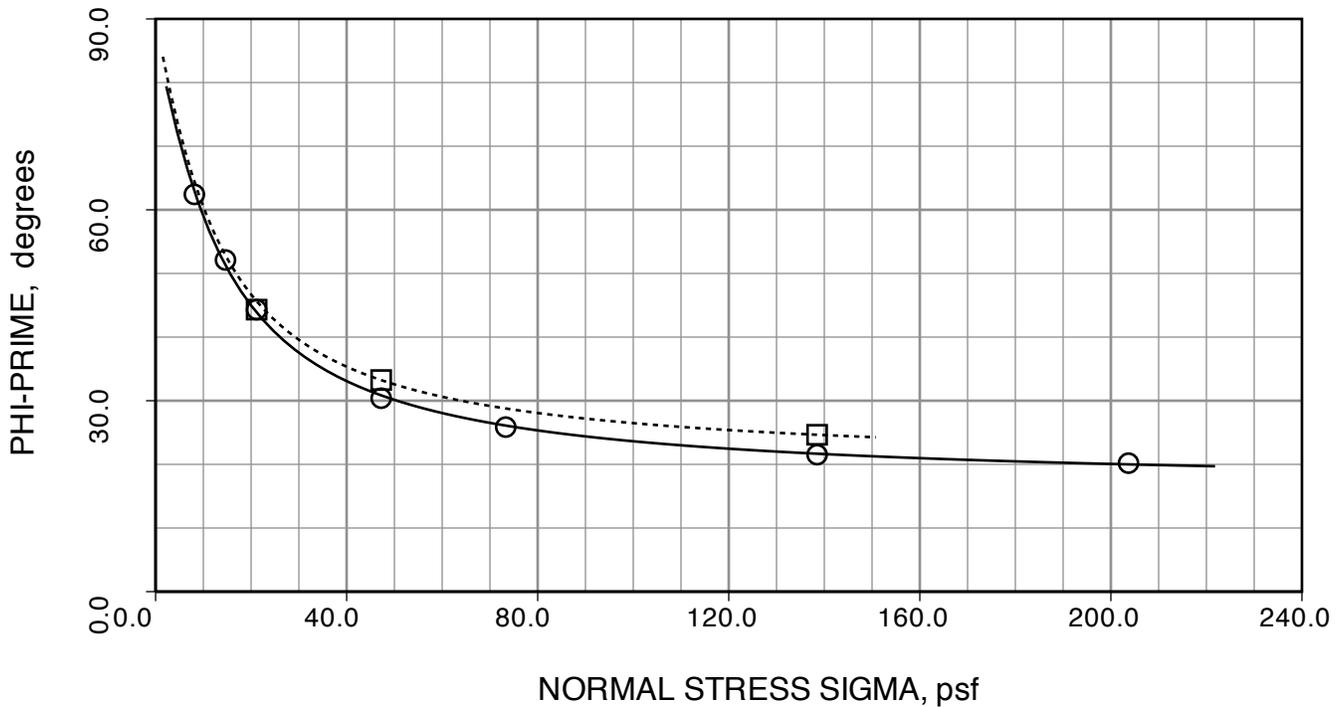
RUN: 6/04/06

ID#: 24541

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

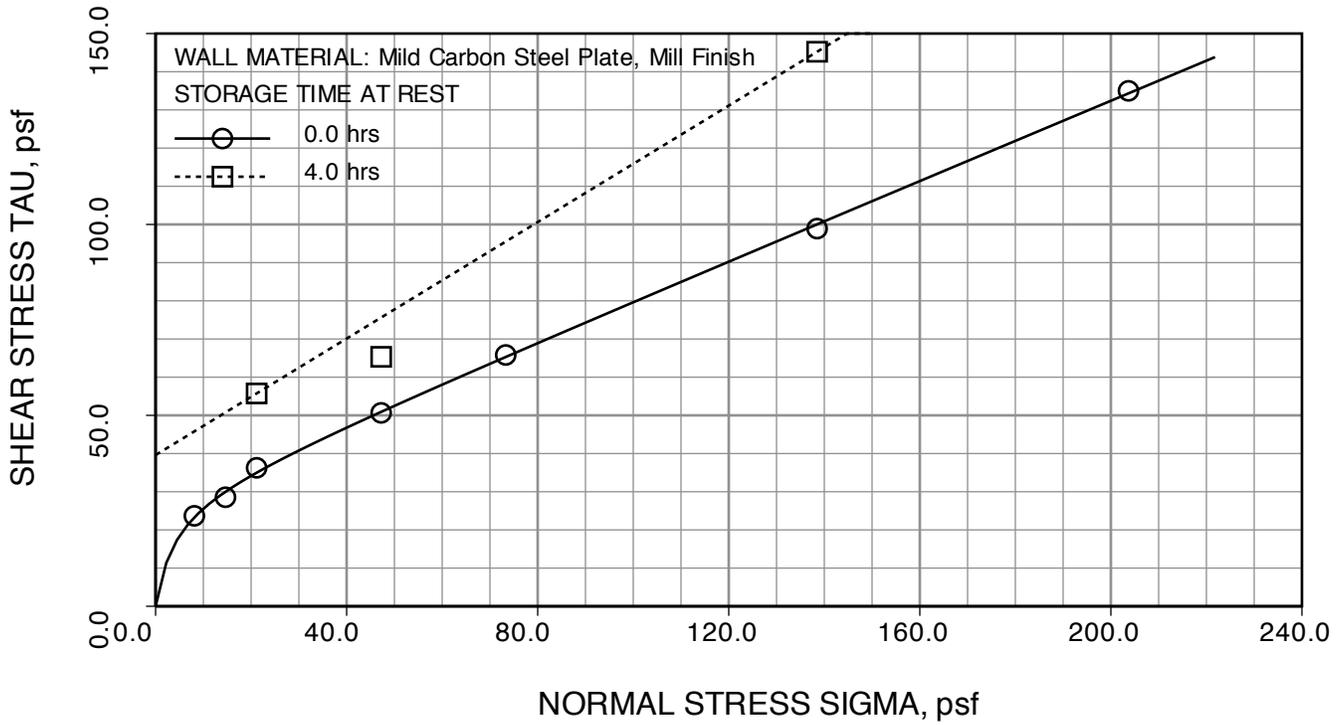
CREATE: 6/03/22

JOB#: 10057

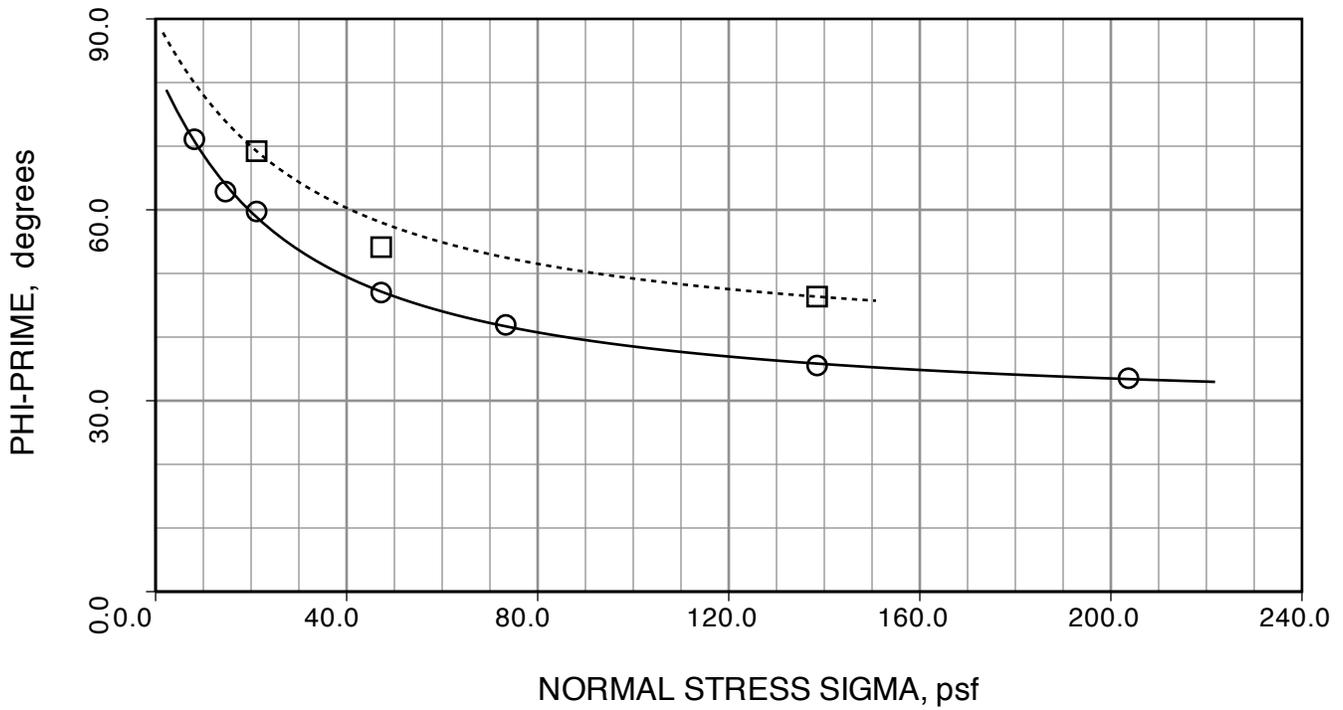
RUN: 6/04/06

ID#: 24541

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

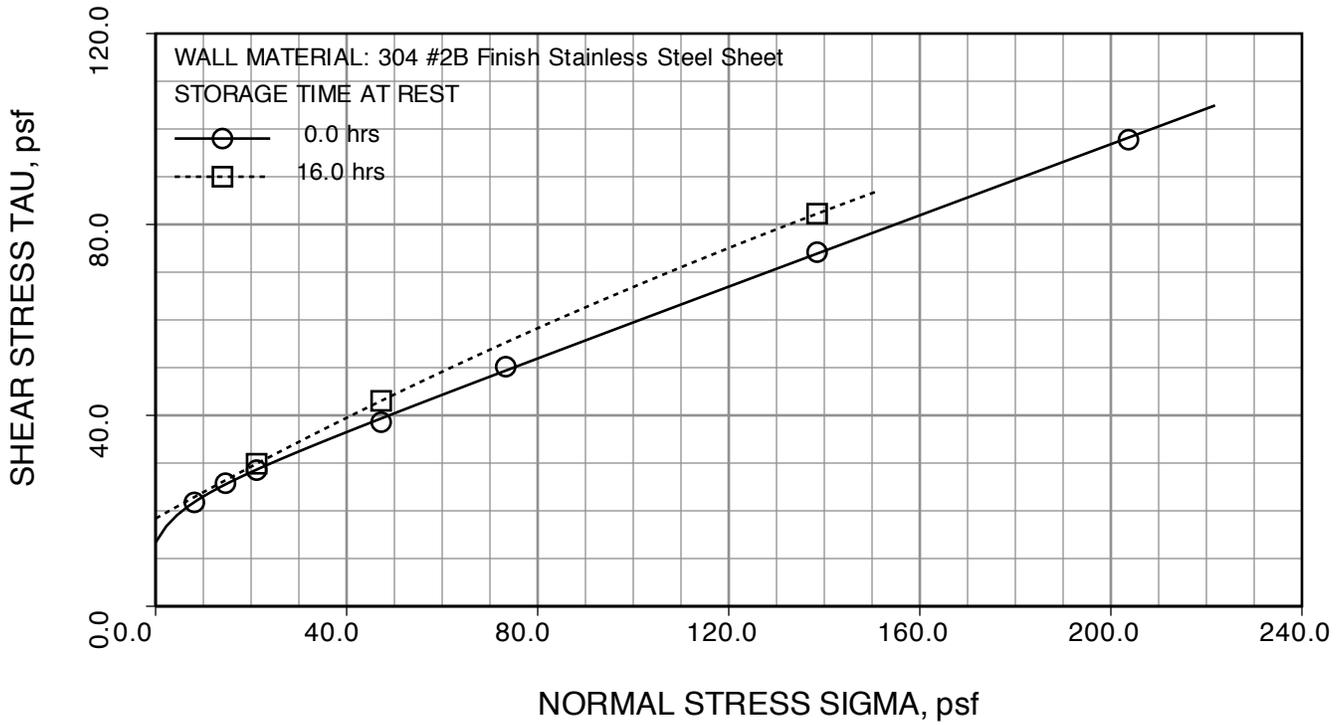
CREATE: 6/03/22

JOB#: 10057

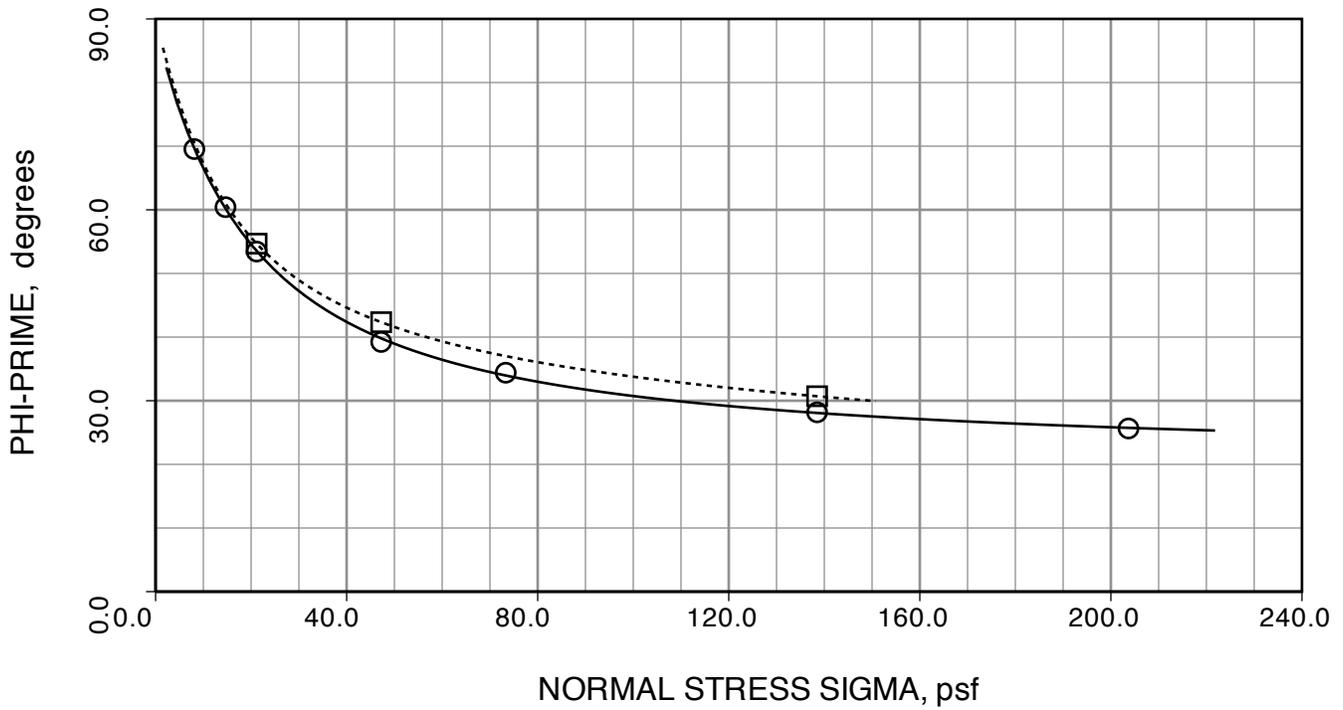
RUN: 6/04/06

ID#: 24541

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

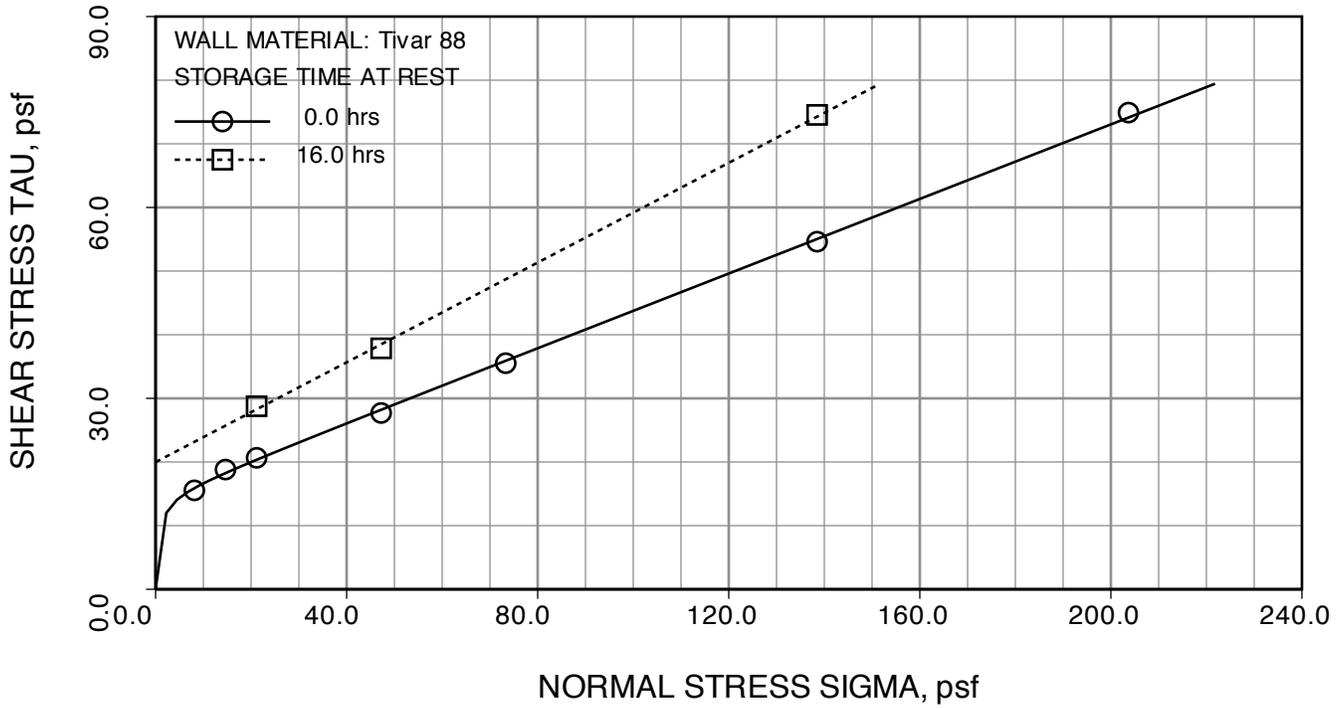
CREATE: 6/03/22

JOB#: 10057

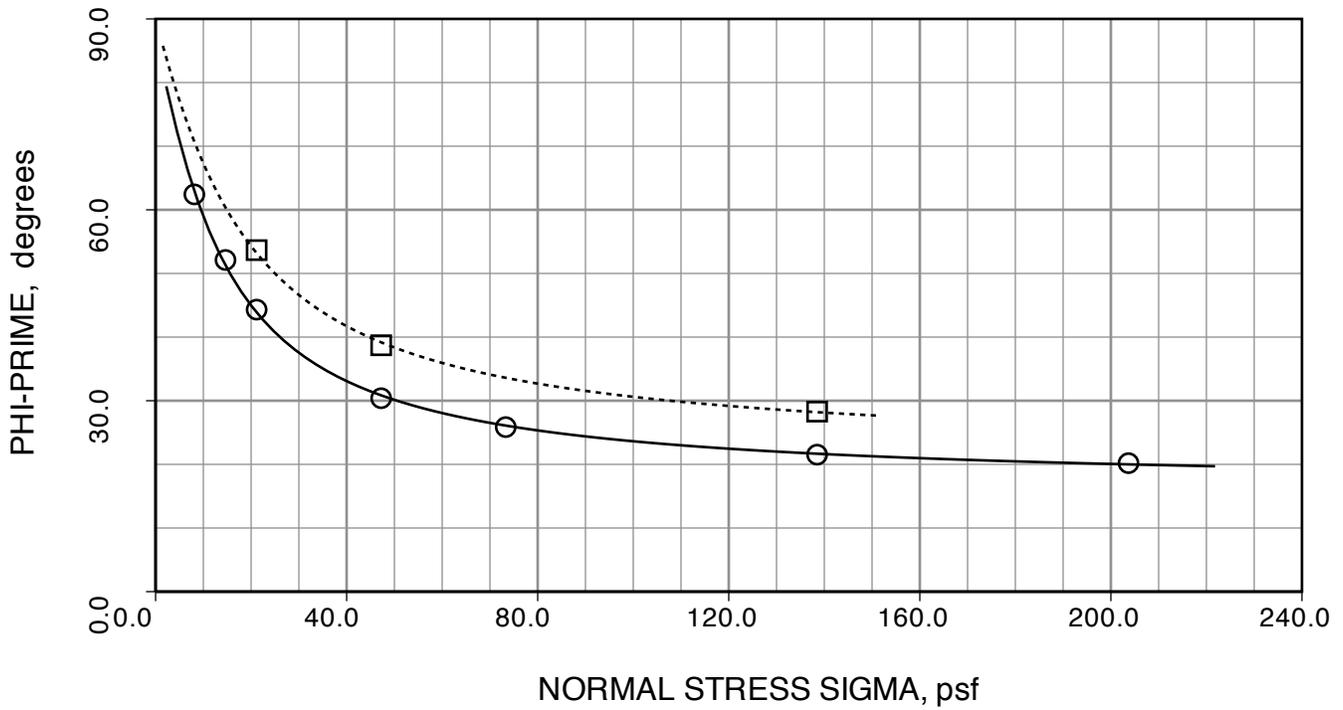
RUN: 6/04/06

ID#: 24541

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

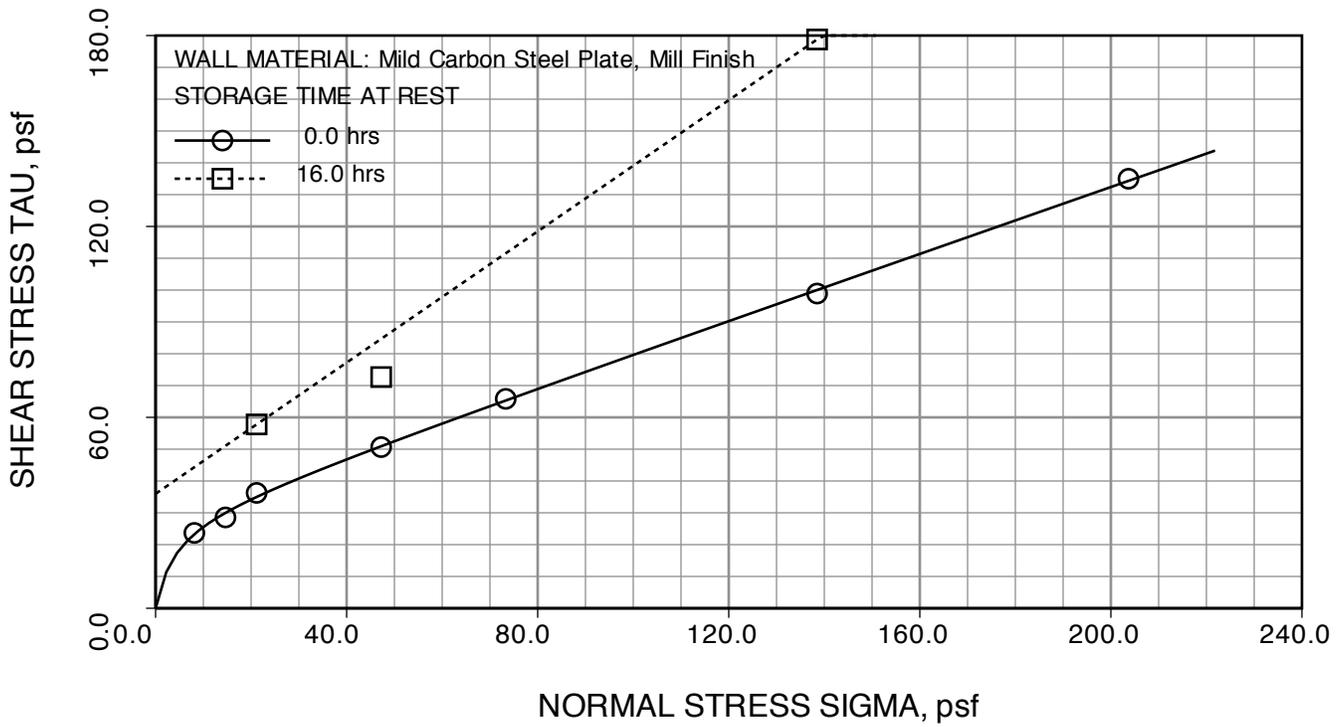
CREATE: 6/03/22

JOB#: 10057

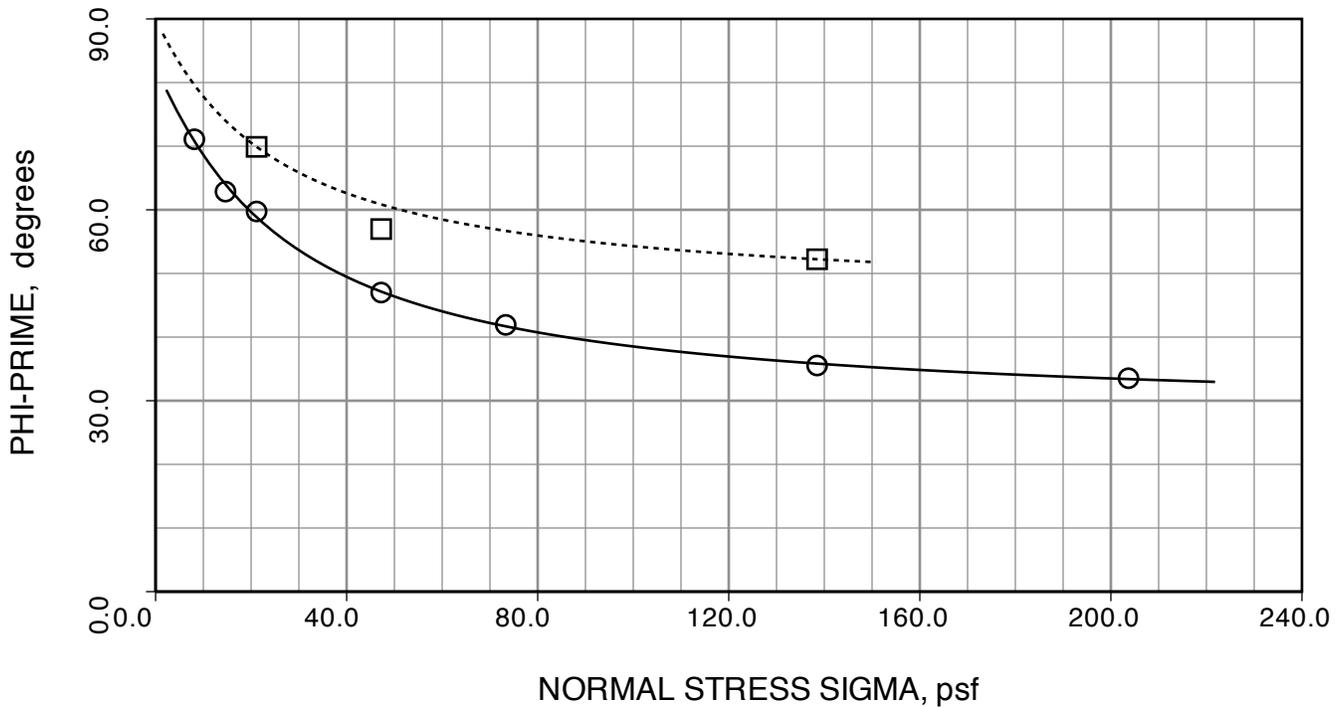
RUN: 6/04/06

ID#: 24541

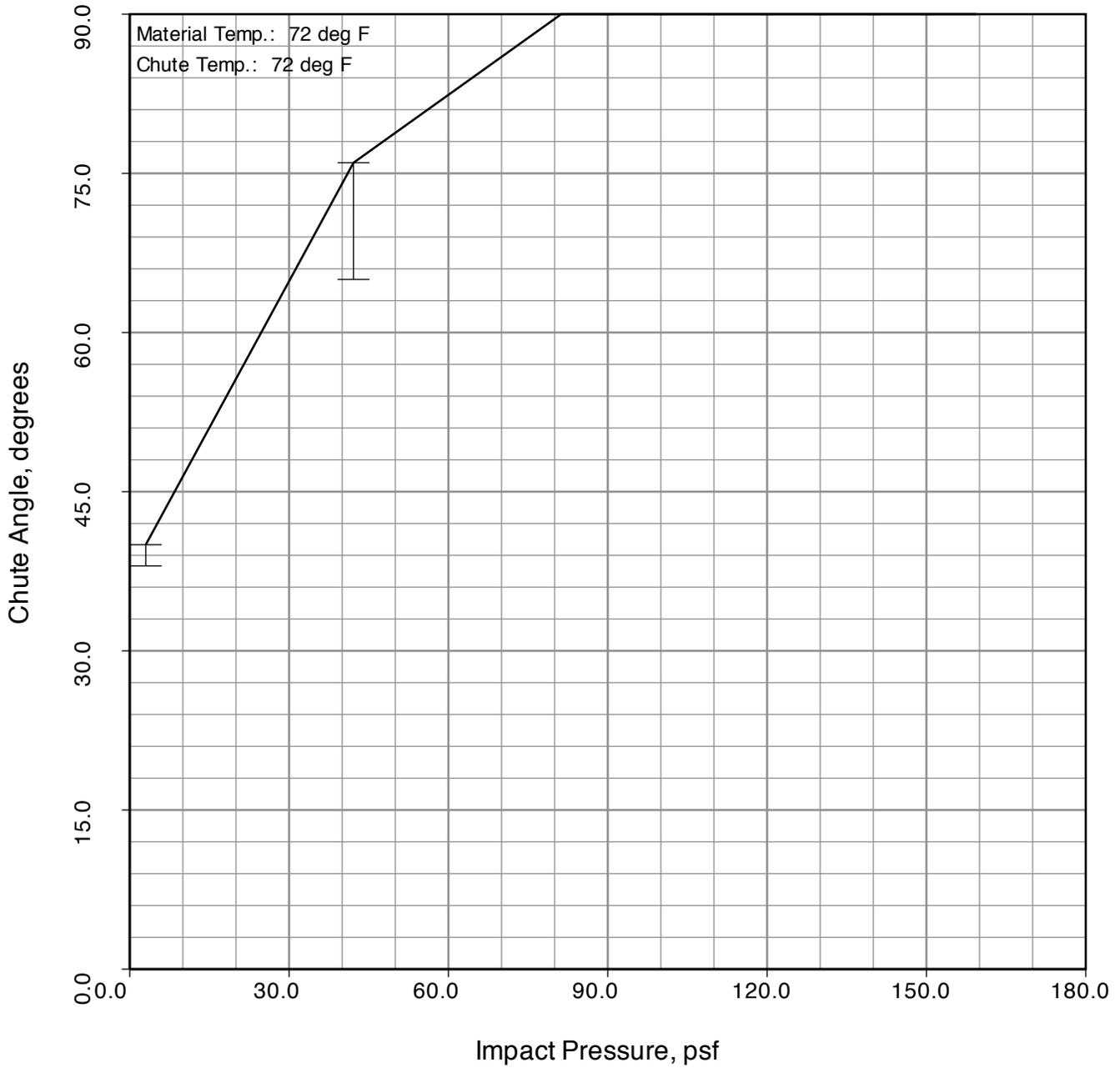
WALL YIELD LOCUS



WALL FRICTION ANGLE



Chute Angles versus Impact Pressure
for 304 #2B Finish Stainless Steel Sheet



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

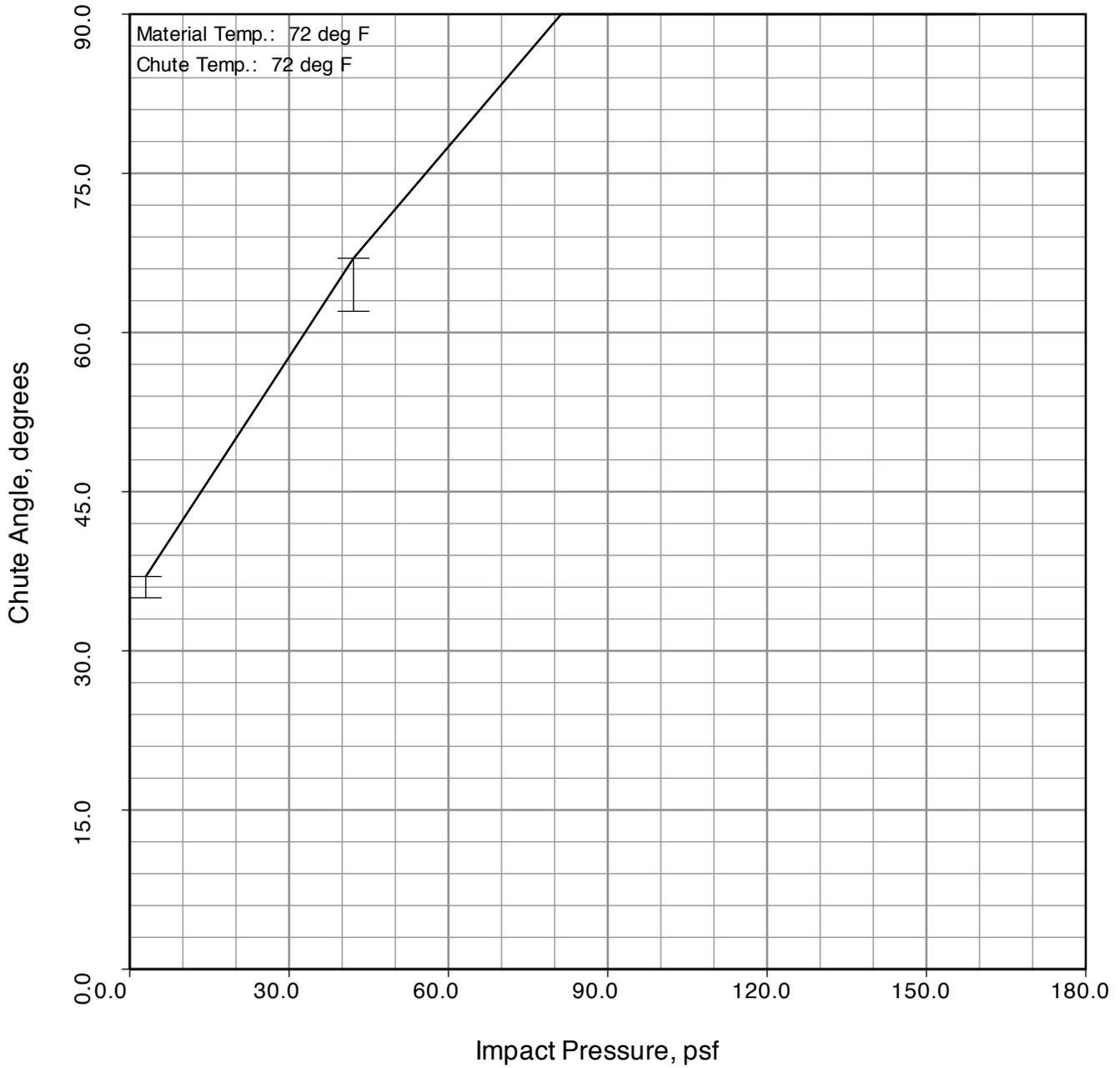
CREATE: 6/03/22

RUN: 6/04/06

JOB#: 10057

ID#: 24541

Chute Angles versus Impact Pressure for Tivar 88



BULK MATERIAL: Slime Tailings GABT-7

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

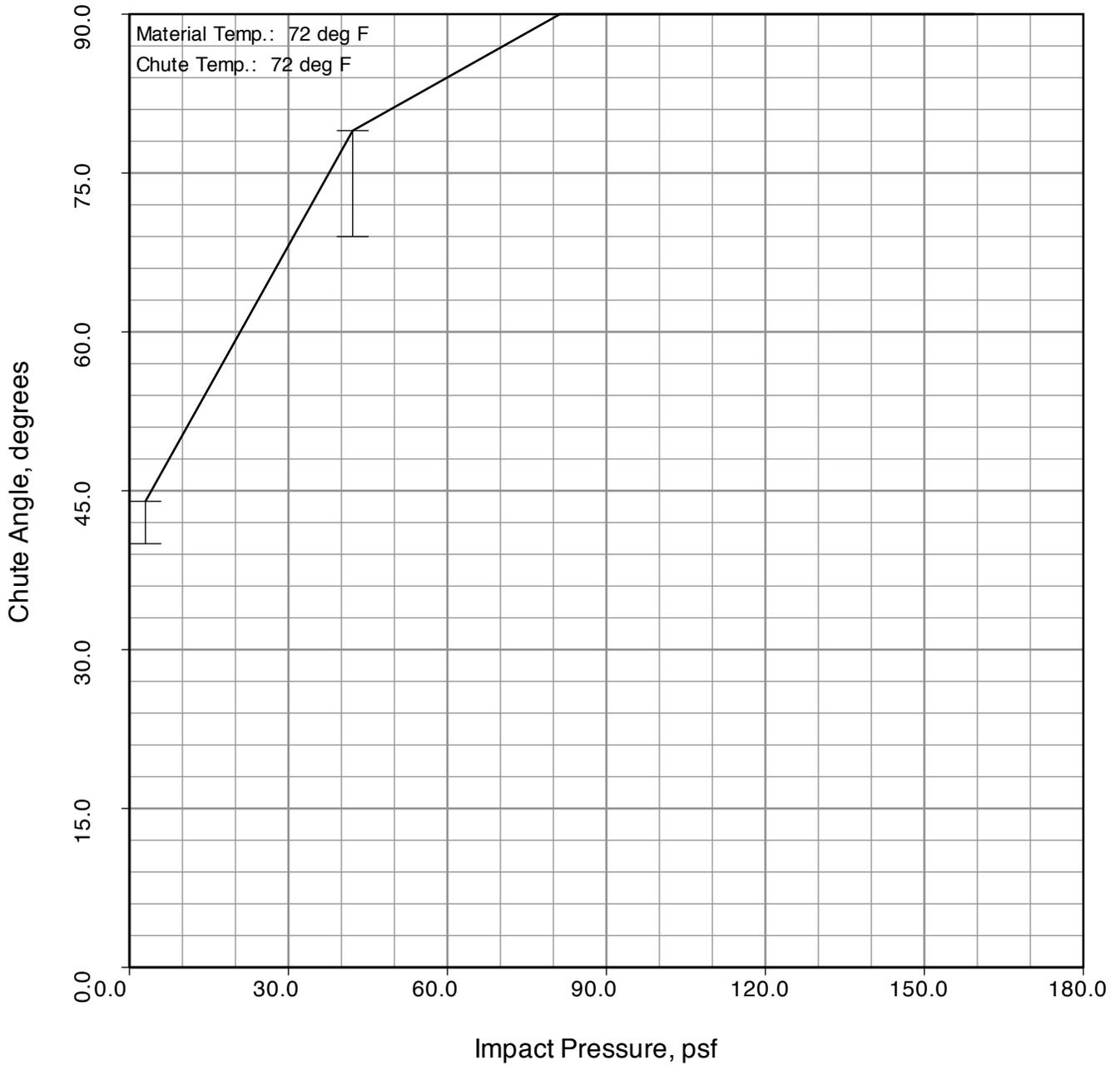
CREATE: 6/03/22

RUN: 6/04/06

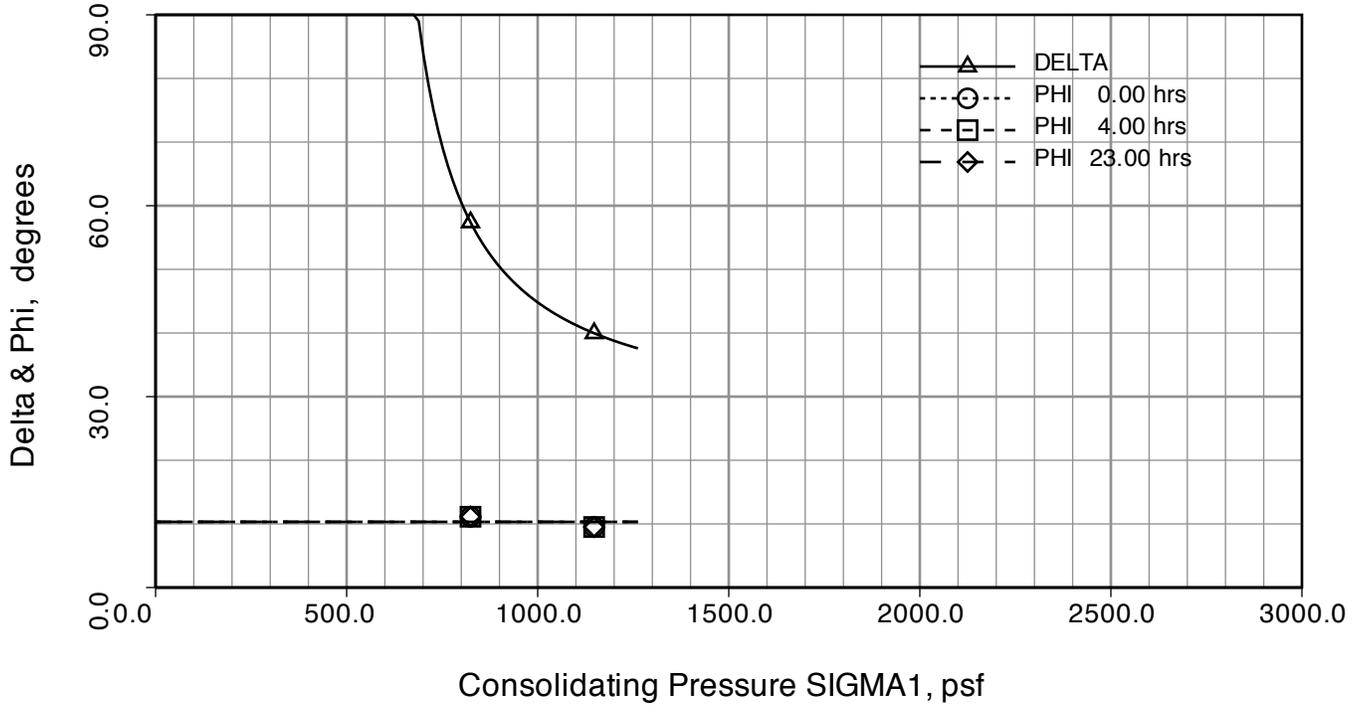
JOB#: 10057

ID#: 24541

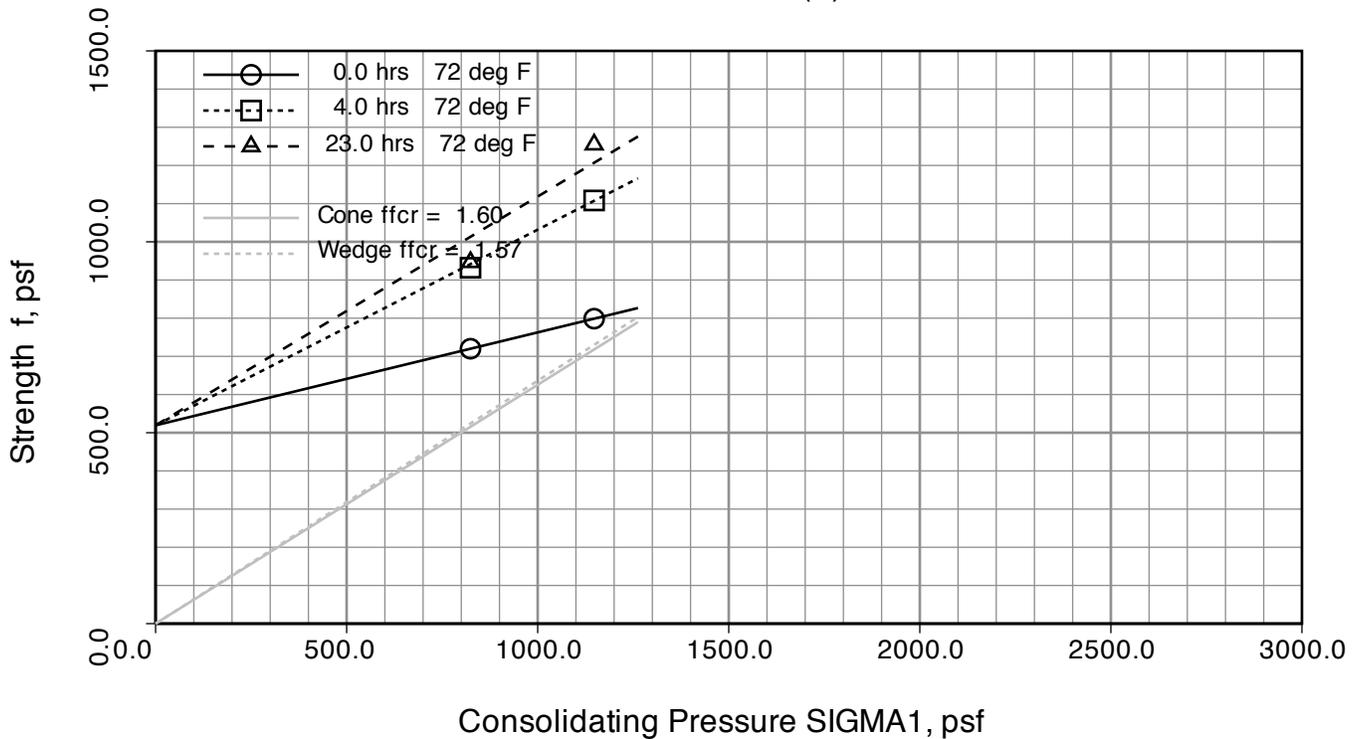
Chute Angles versus Impact Pressure
for Mild Carbon Steel Plate, Mill Finish



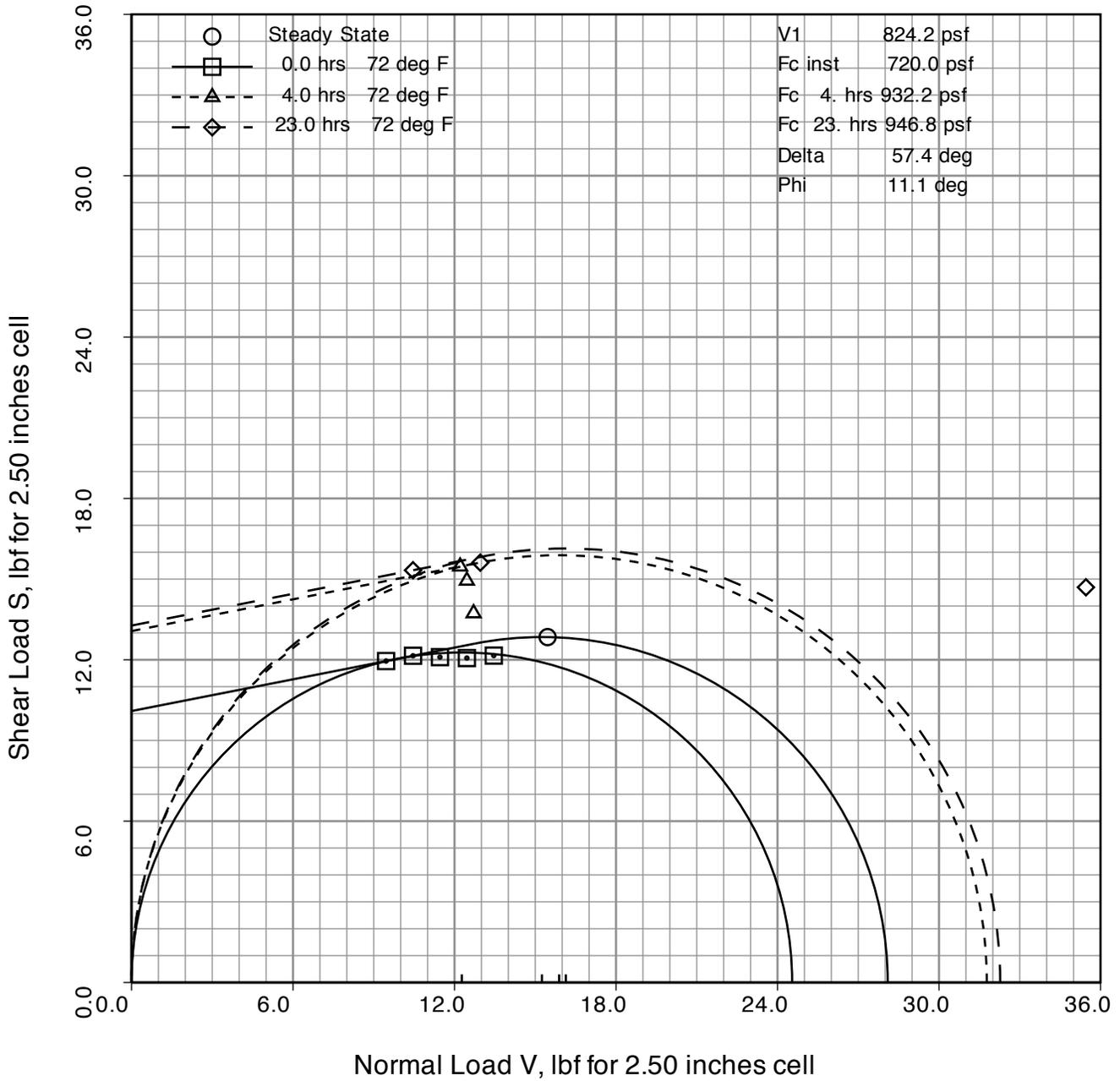
DELTA & PHI RELATIONS



FLOW FUNCTION(S)



YIELD LOCUS



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

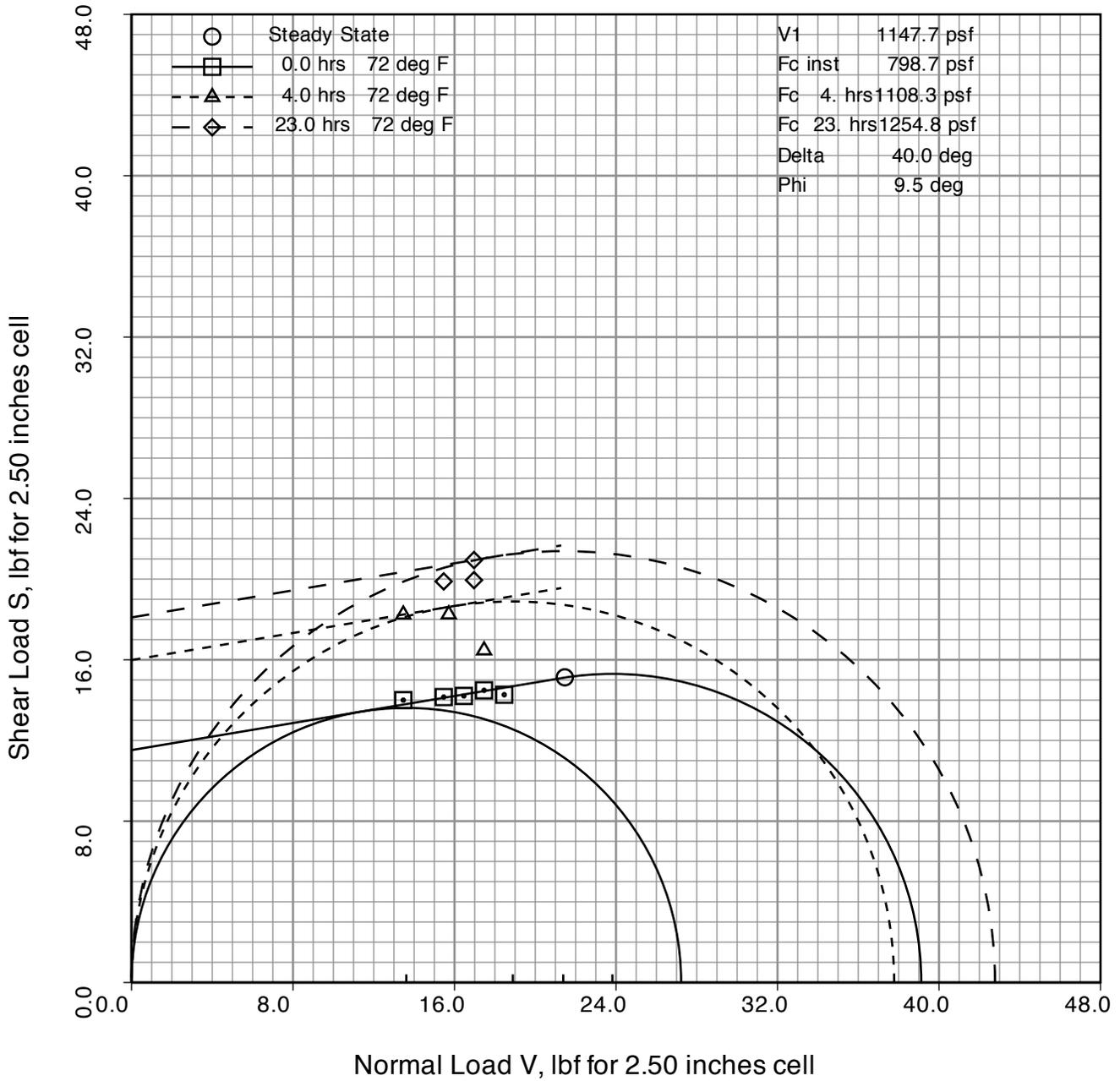
CREATE: 6/03/23

RUN: 6/04/06

JOB#: 10057

ID#: 24542

YIELD LOCUS



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

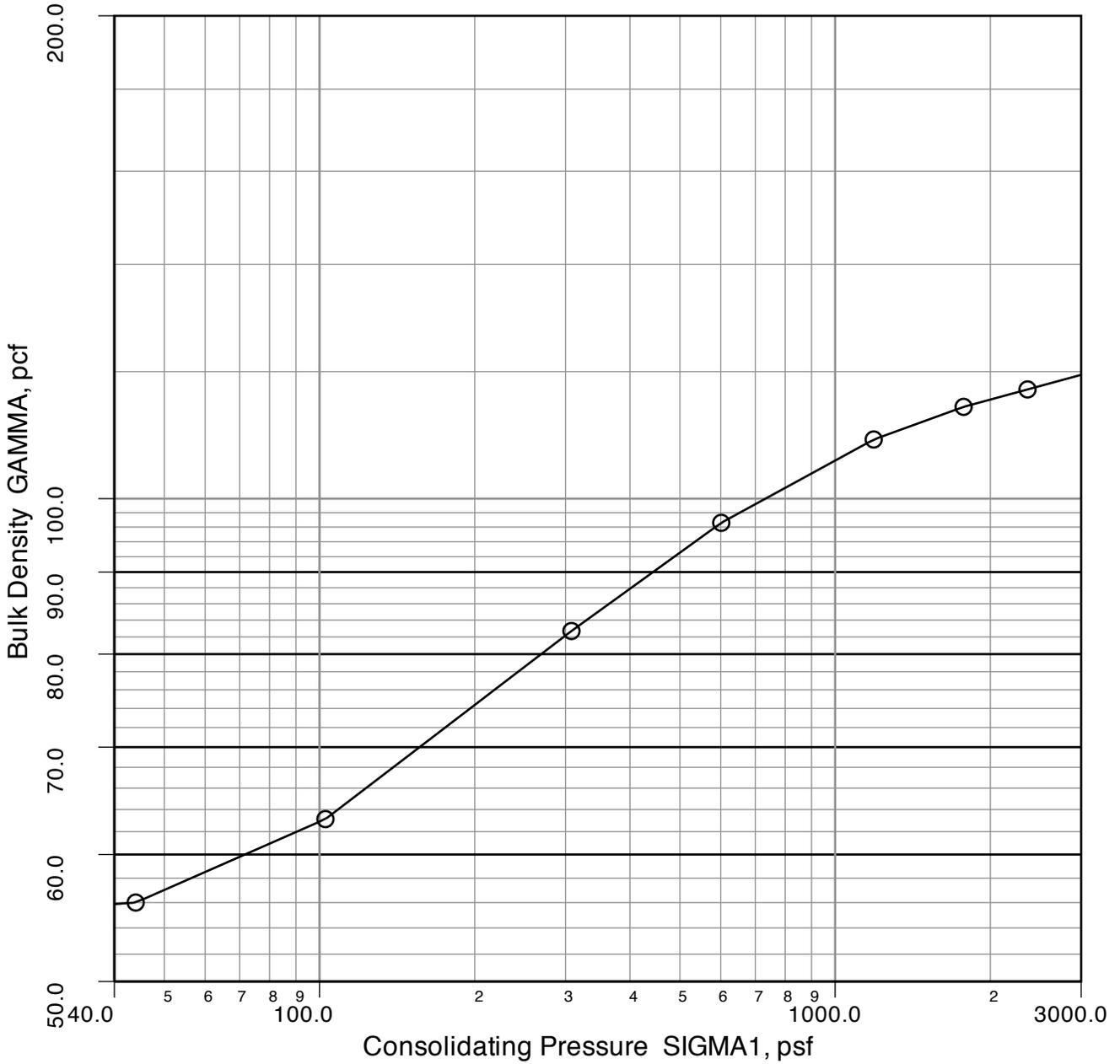
CREATE: 6/03/23

RUN: 6/04/06

JOB#: 10057

ID#: 24542

BULK DENSITY VS. CONSOLIDATING PRESSURE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

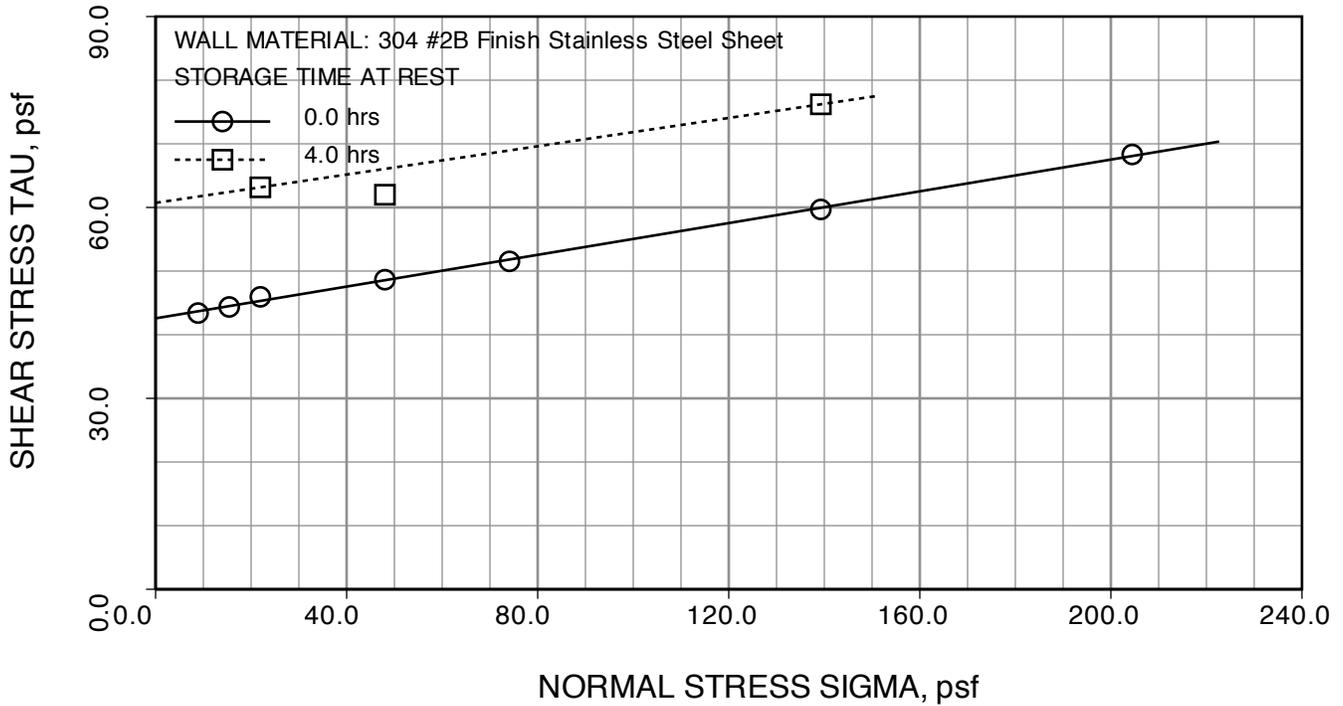
CREATE: 6/03/23

JOB#: 10057

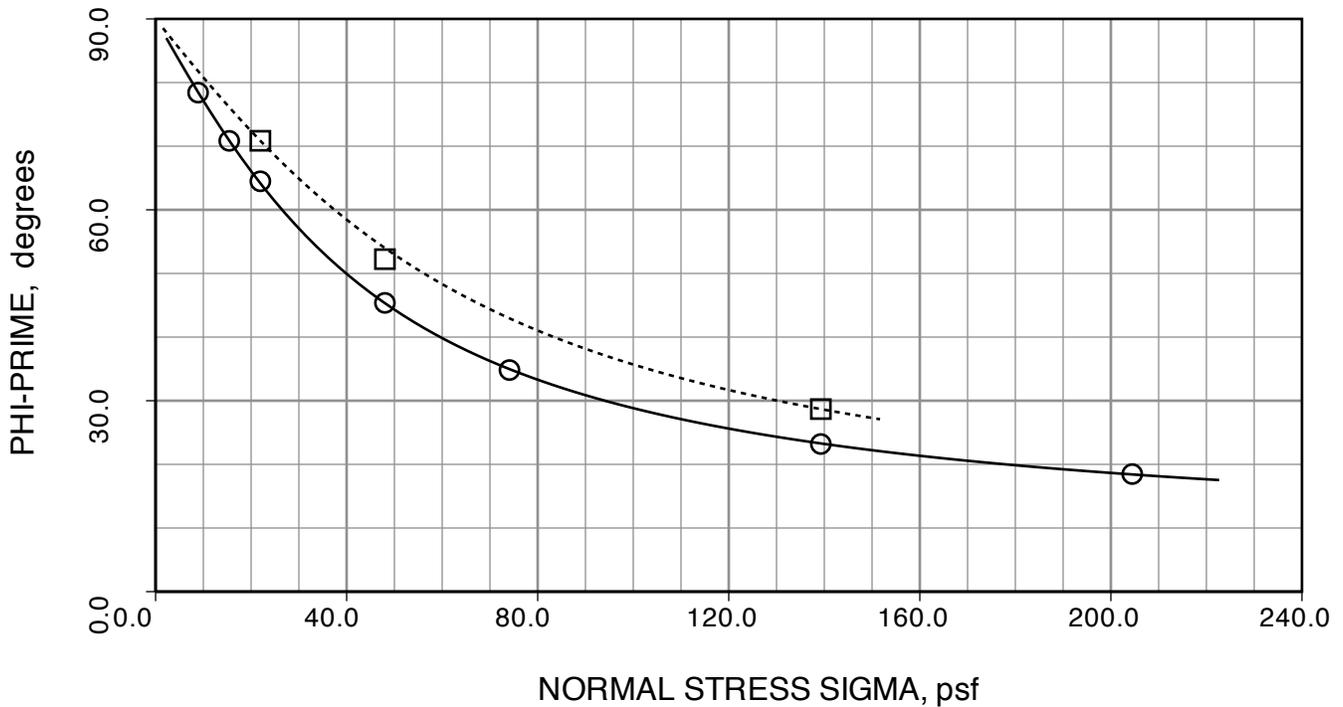
RUN: 6/04/06

ID#: 24542

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

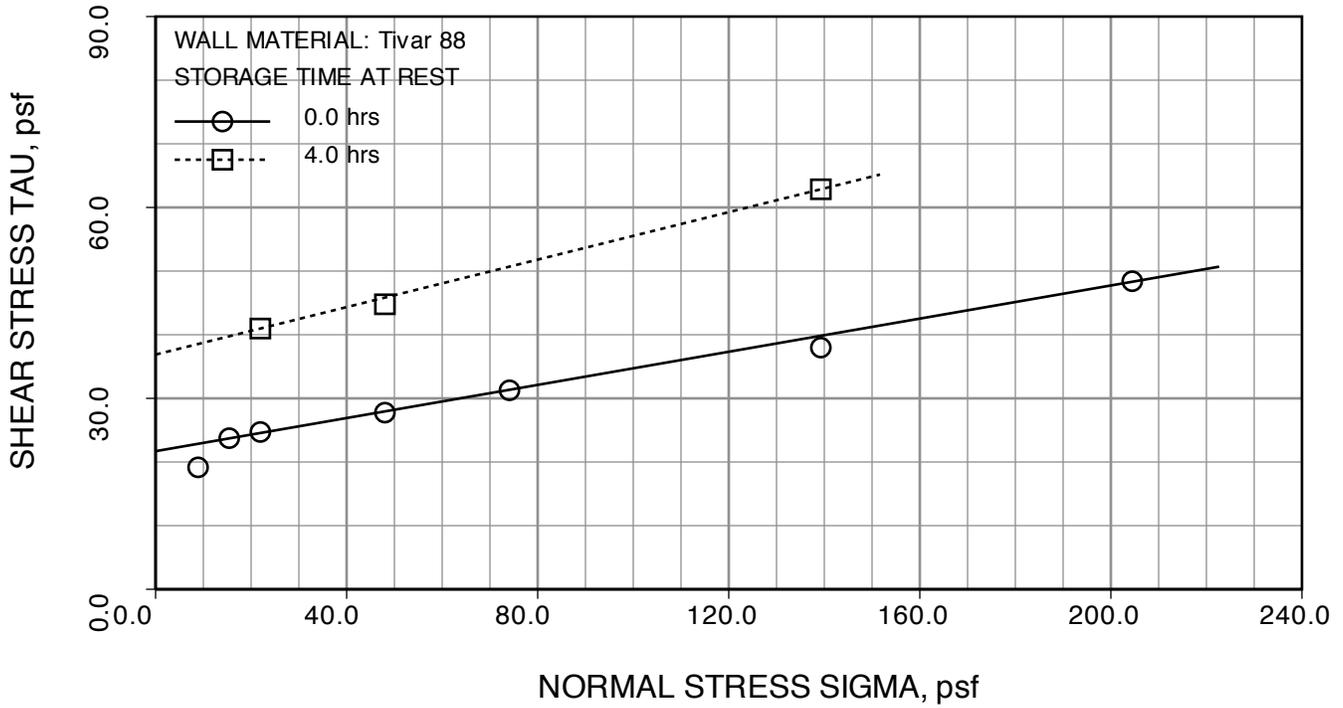
CREATE: 6/03/23

RUN: 6/04/06

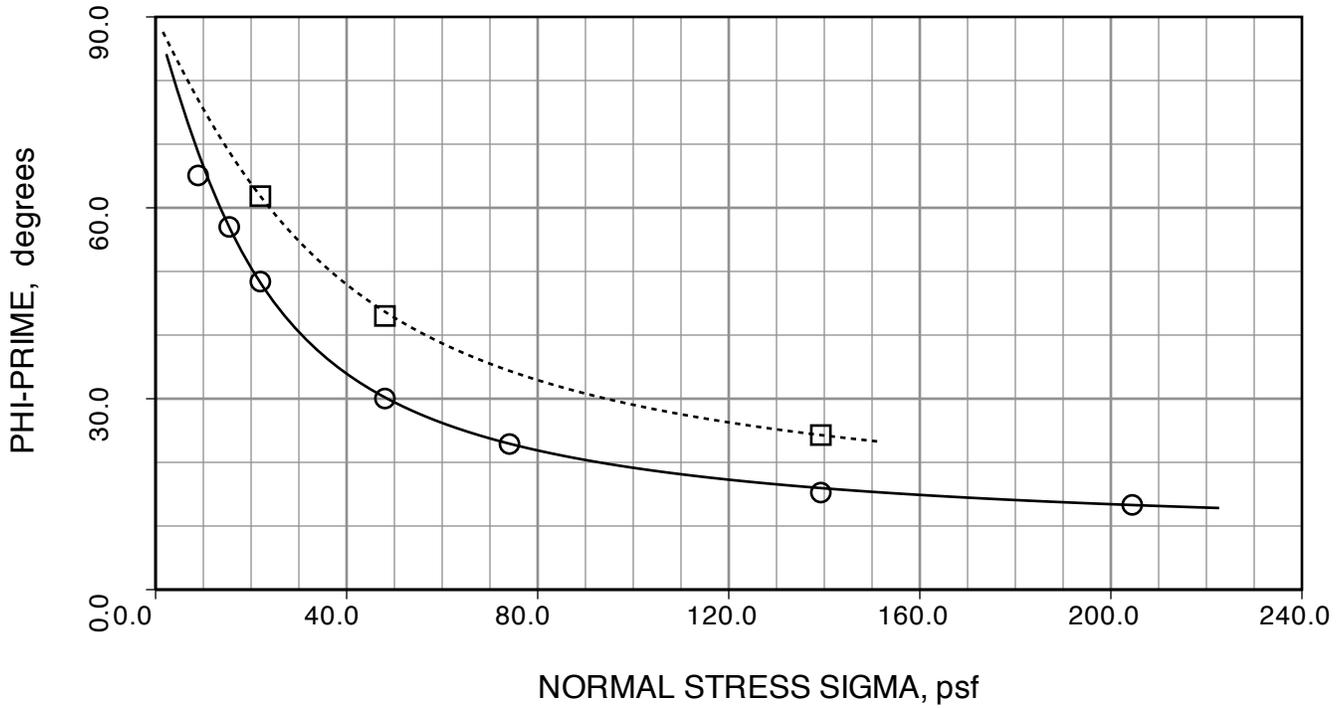
JOB#: 10057

ID#: 24542

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

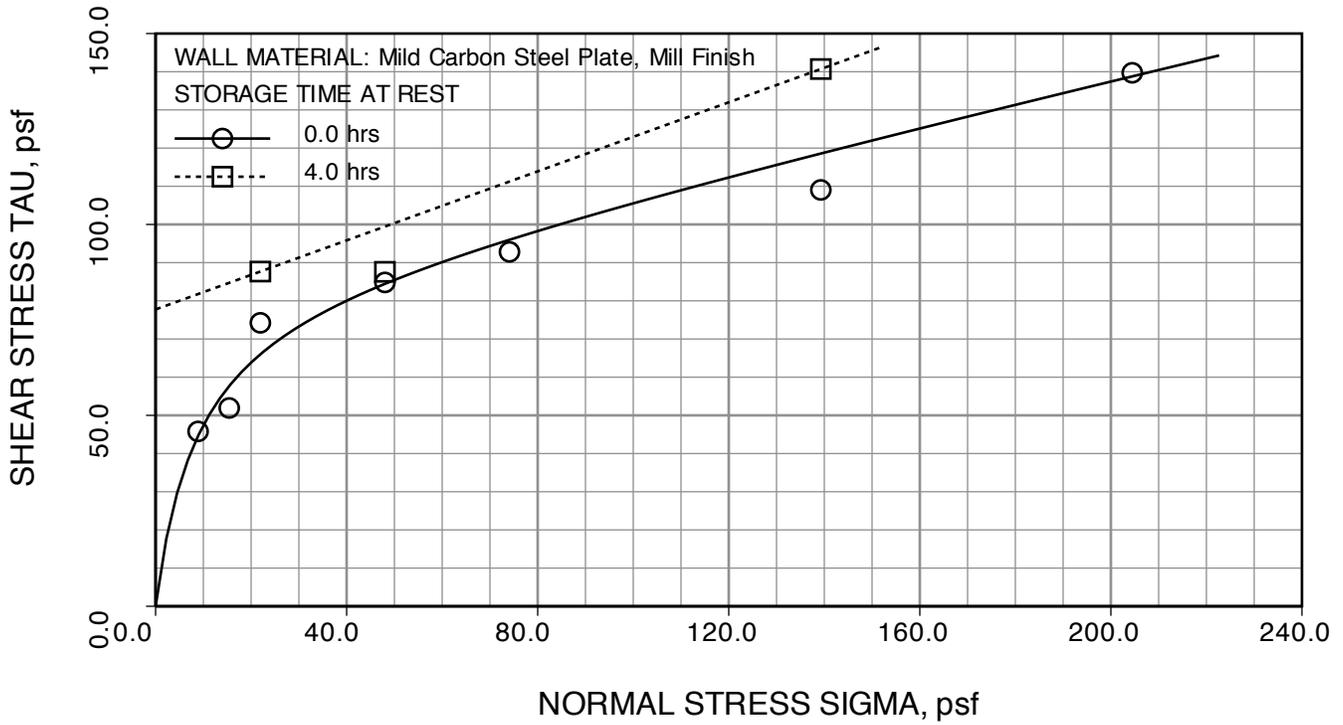
CREATE: 6/03/23

JOB#: 10057

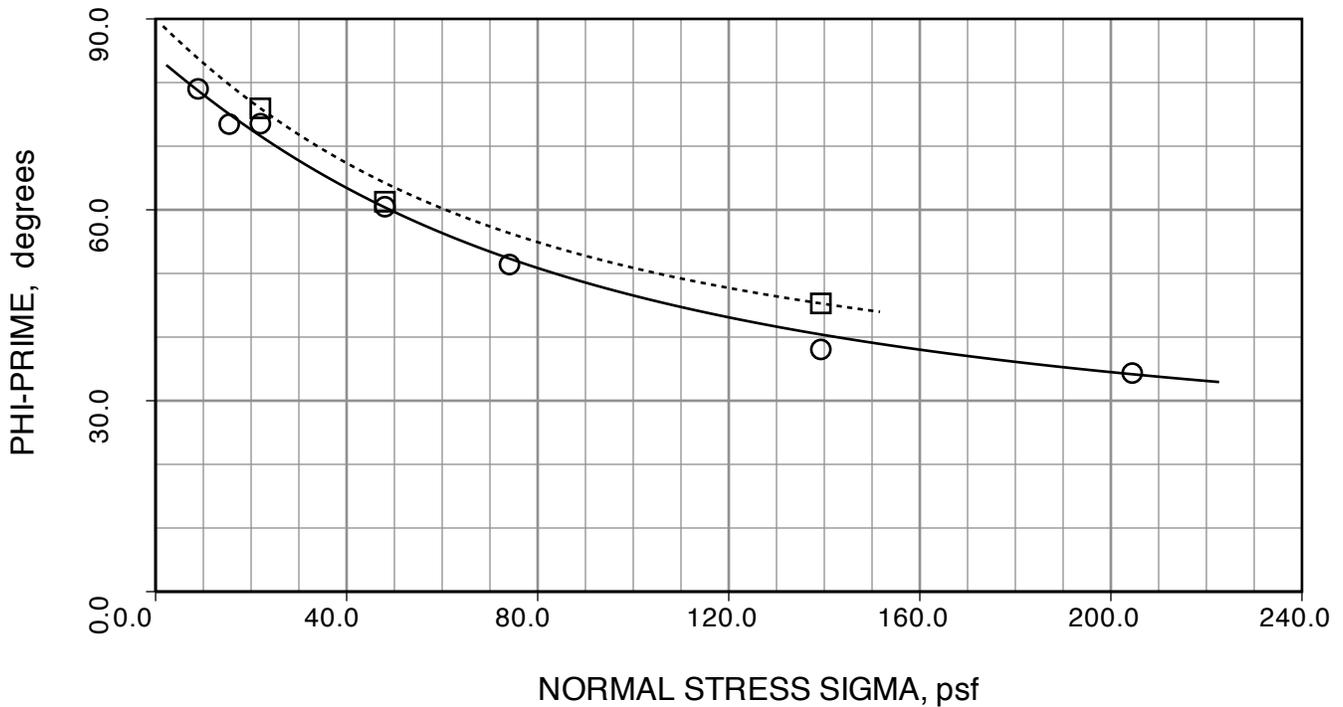
RUN: 6/04/06

ID#: 24542

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

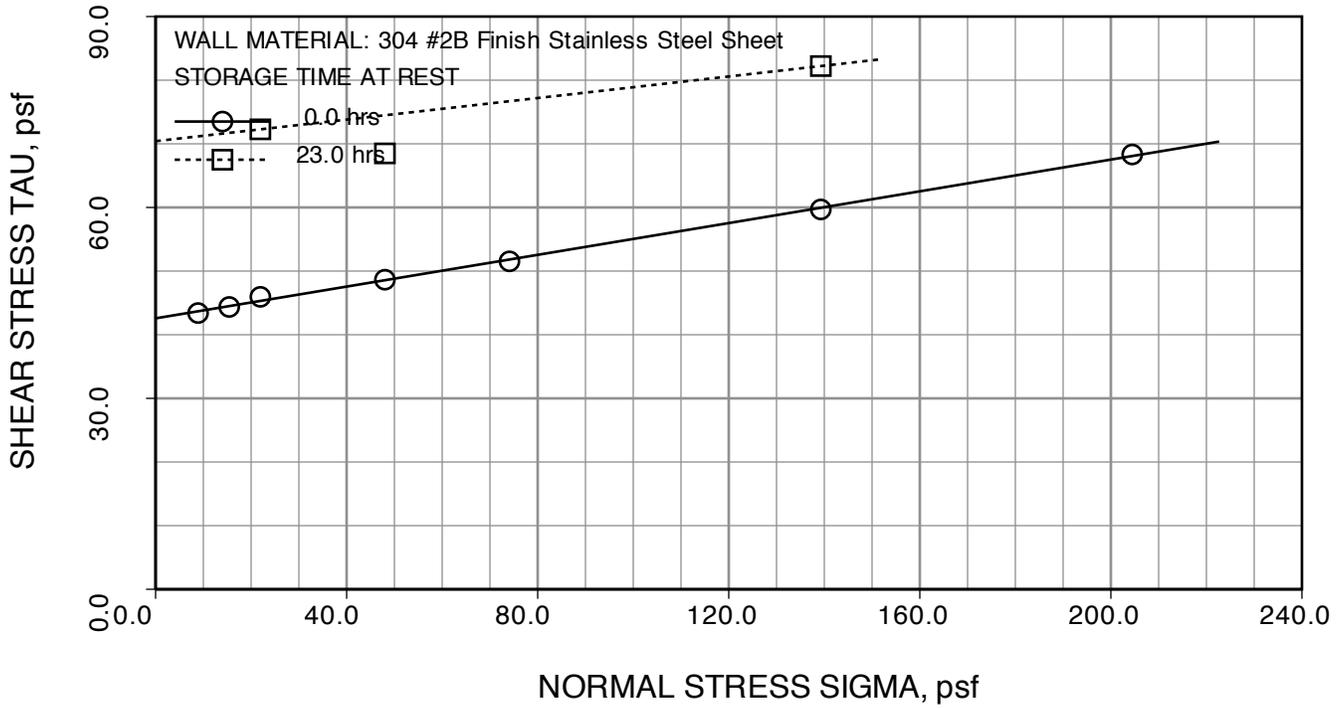
CREATE: 6/03/23

JOB#: 10057

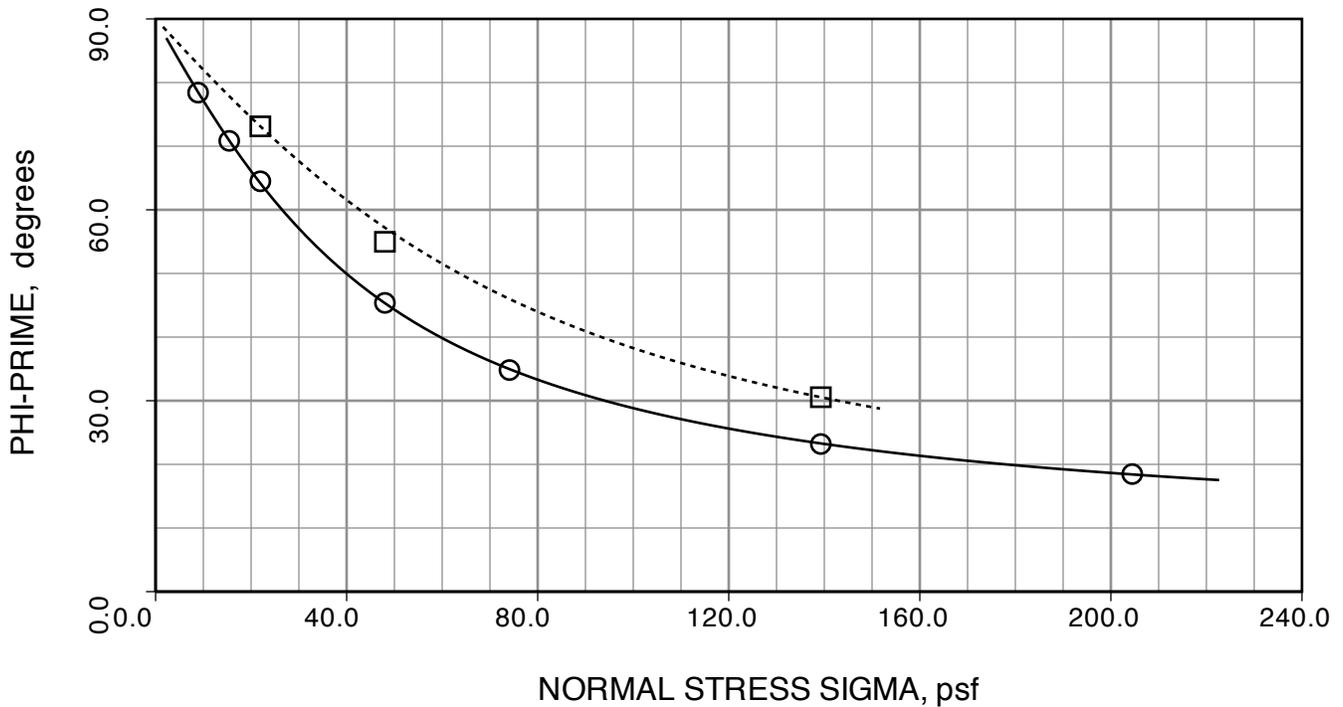
RUN: 6/04/06

ID#: 24542

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

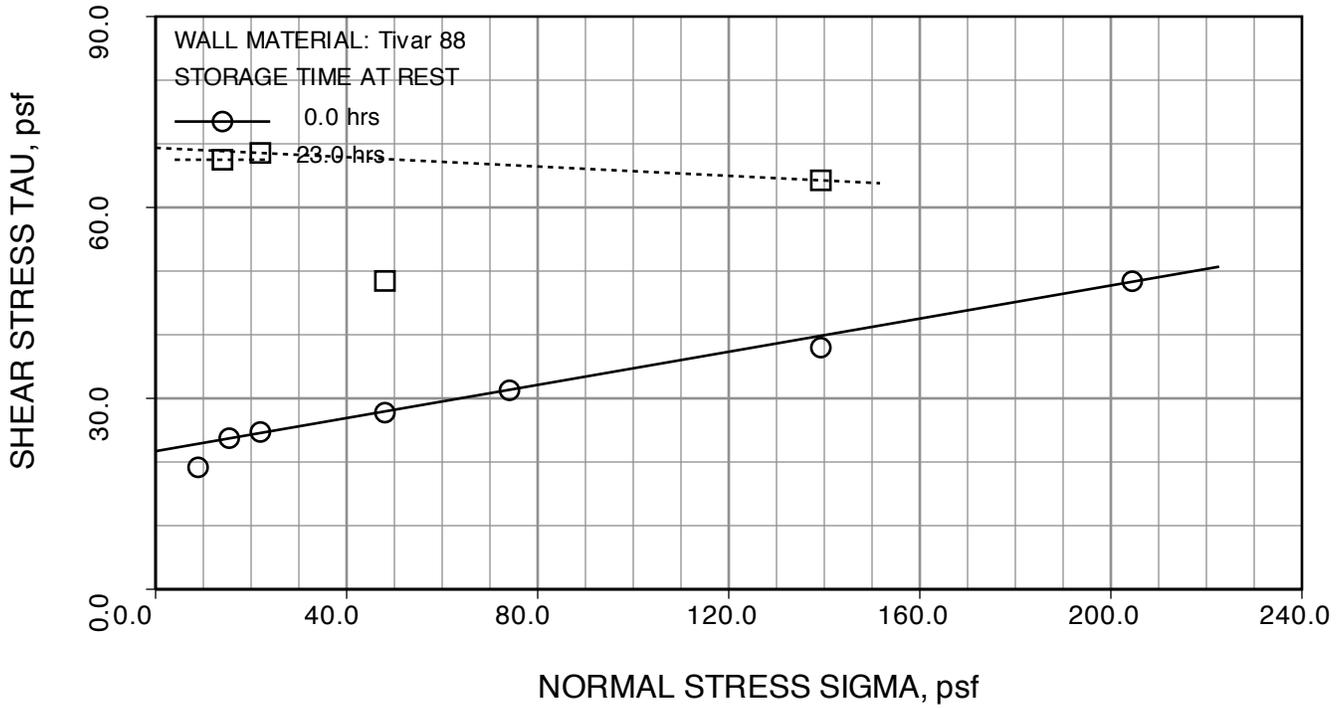
CREATE: 6/03/23

RUN: 6/04/06

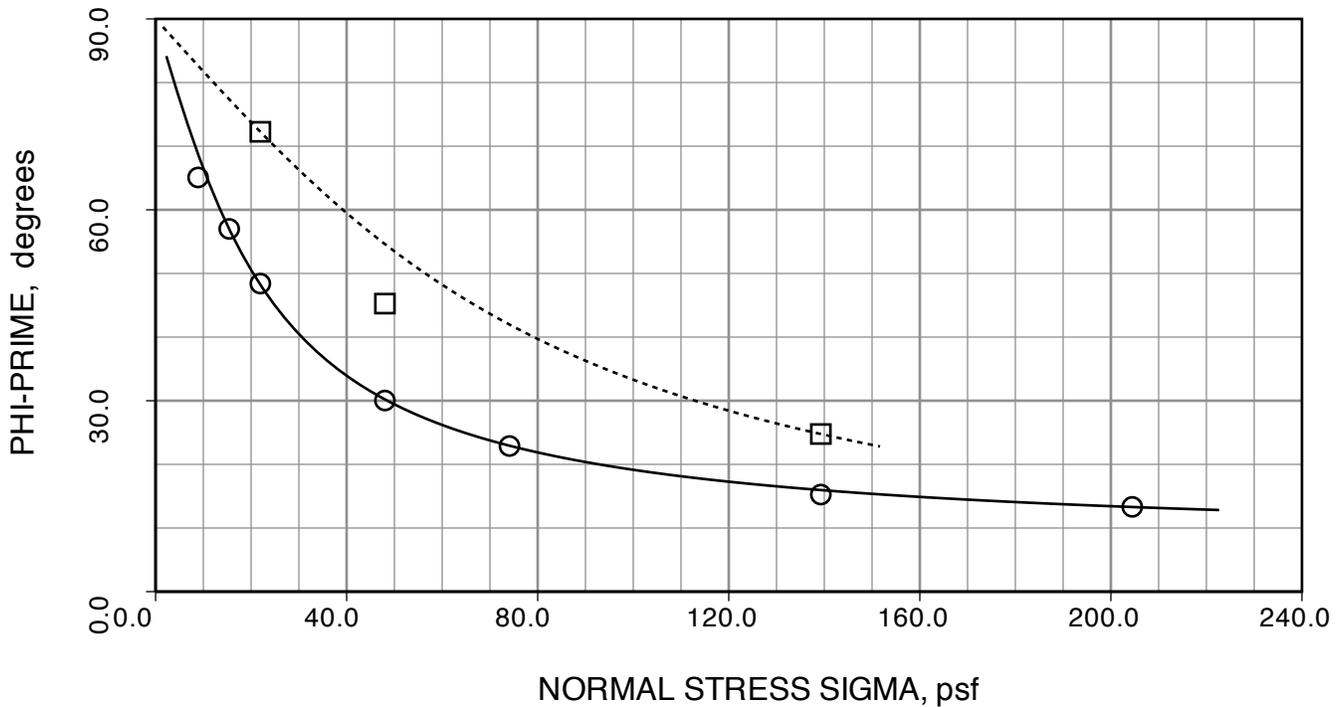
JOB#: 10057

ID#: 24542

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

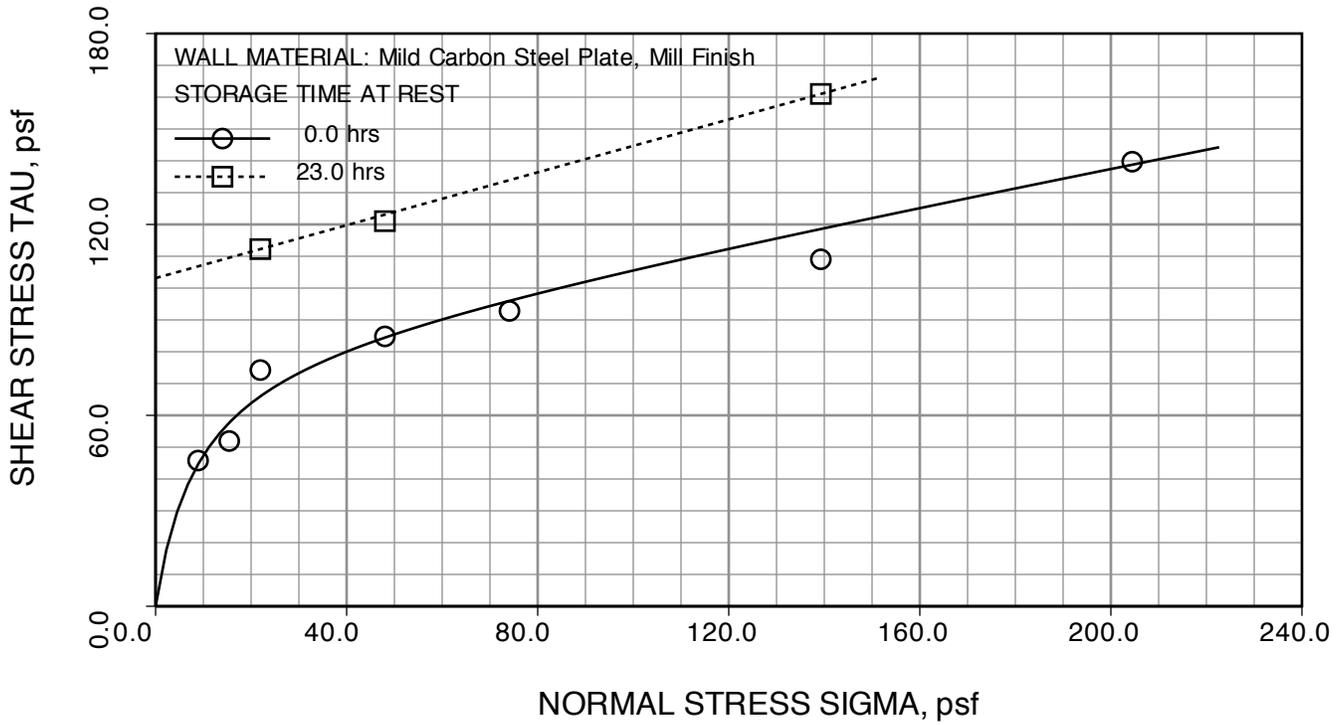
CREATE: 6/03/23

RUN: 6/04/06

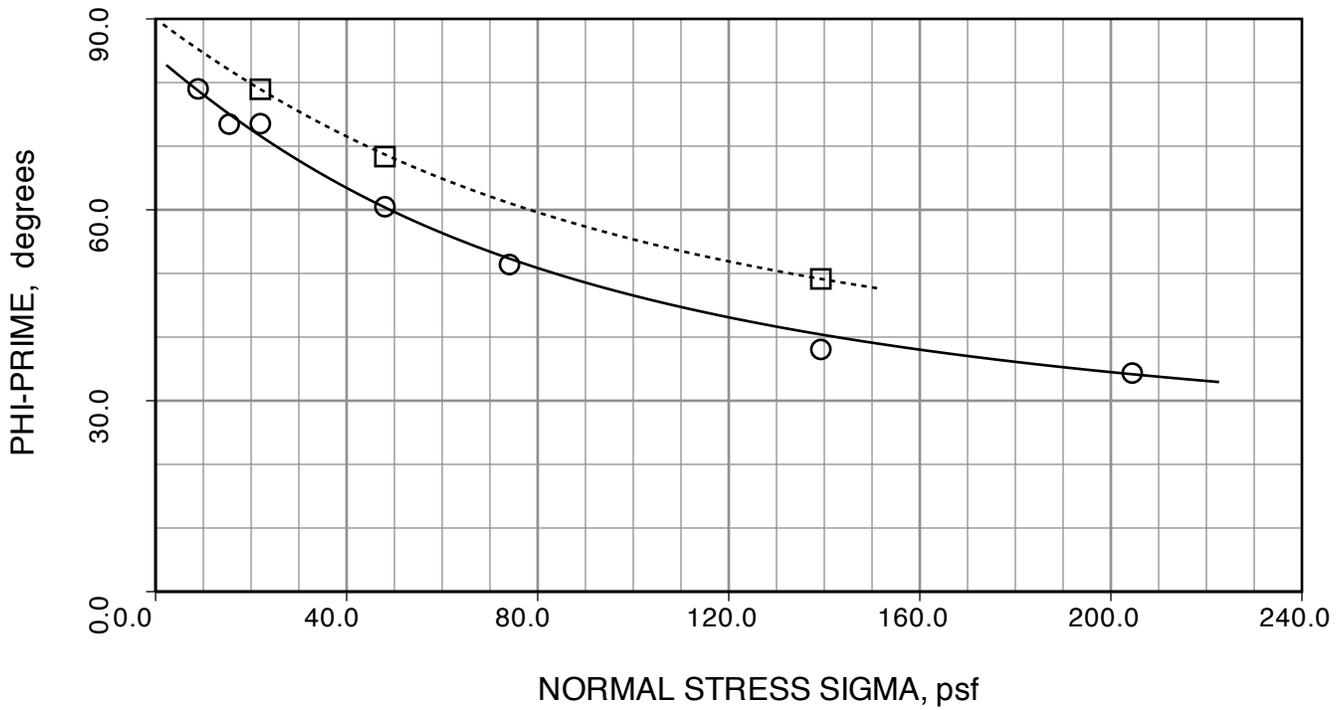
JOB#: 10057

ID#: 24542

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

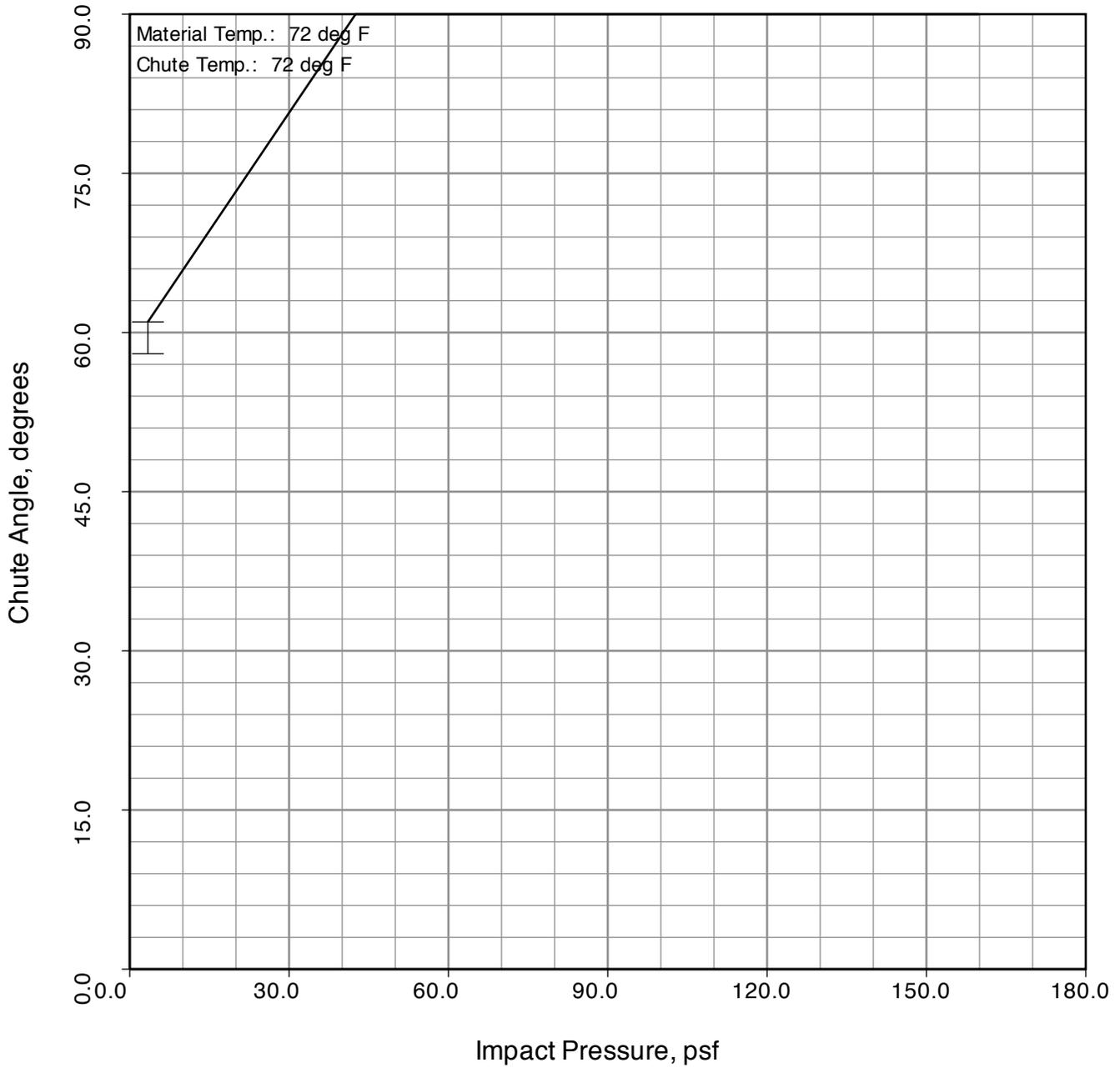
CREATE: 6/03/23

RUN: 6/04/06

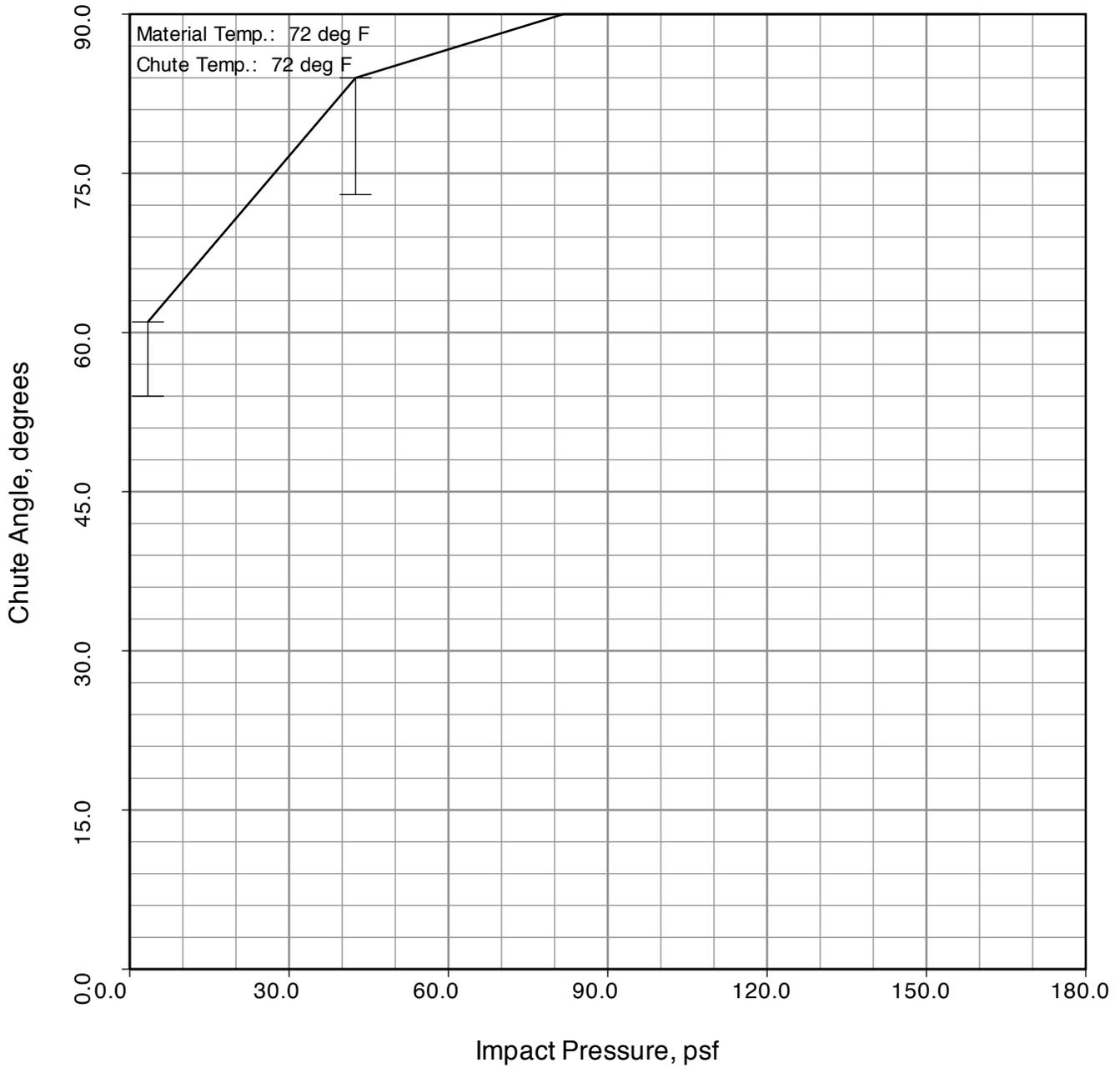
JOB#: 10057

ID#: 24542

Chute Angles versus Impact Pressure
for 304 #2B Finish Stainless Steel Sheet



Chute Angles versus Impact Pressure
for Tivar 88



BULK MATERIAL: 715 Moab Tailings 22-24'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

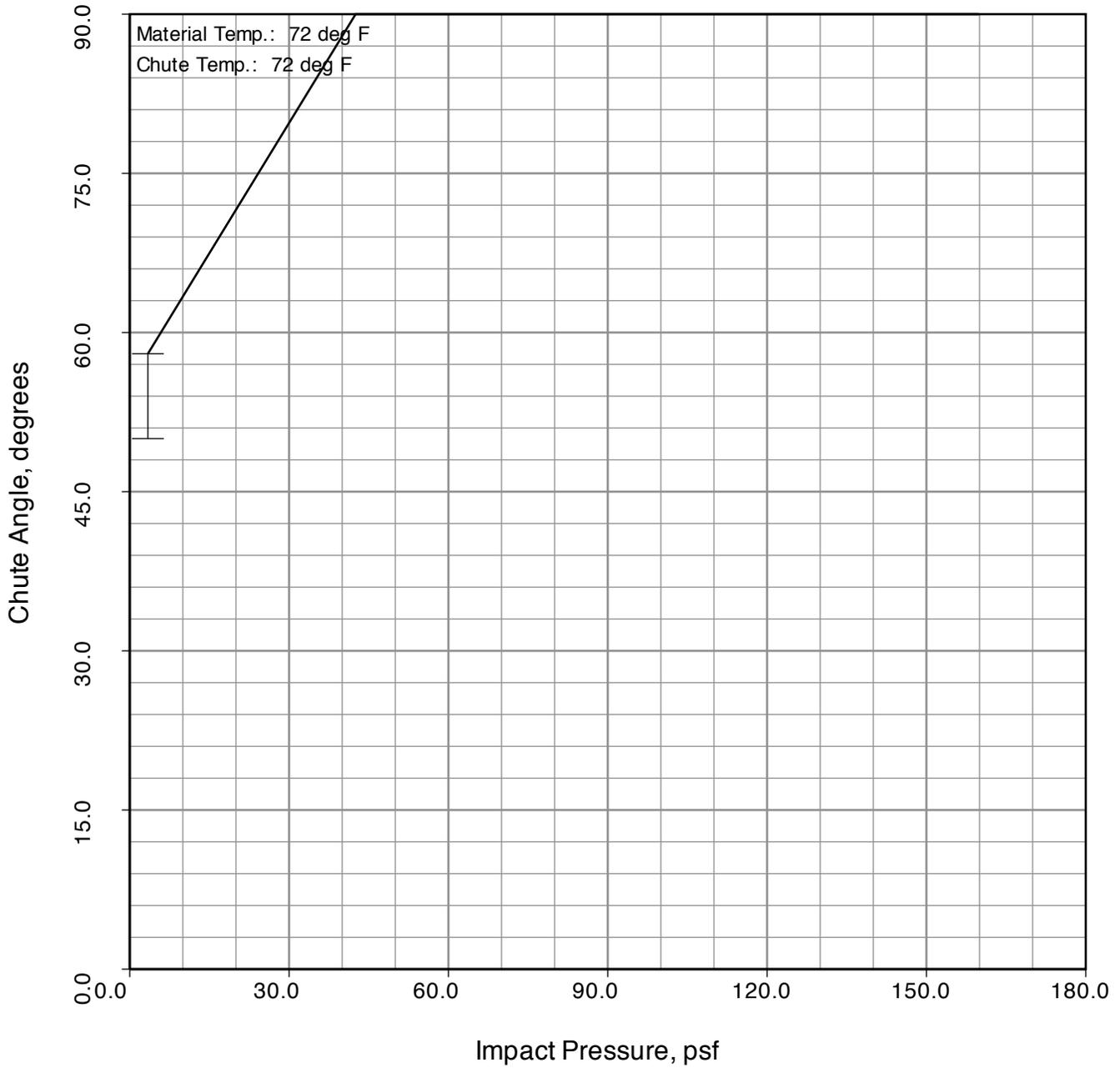
CREATE: 6/03/23

RUN: 6/04/06

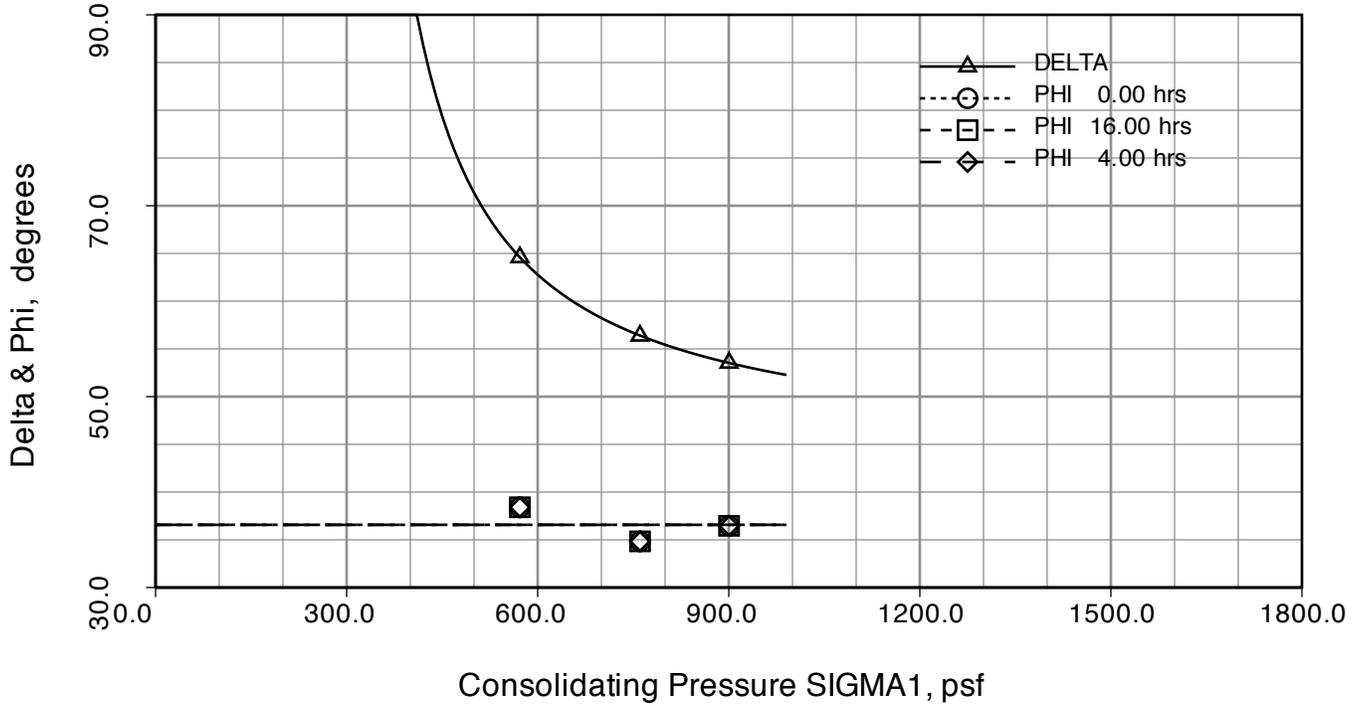
JOB#: 10057

ID#: 24542

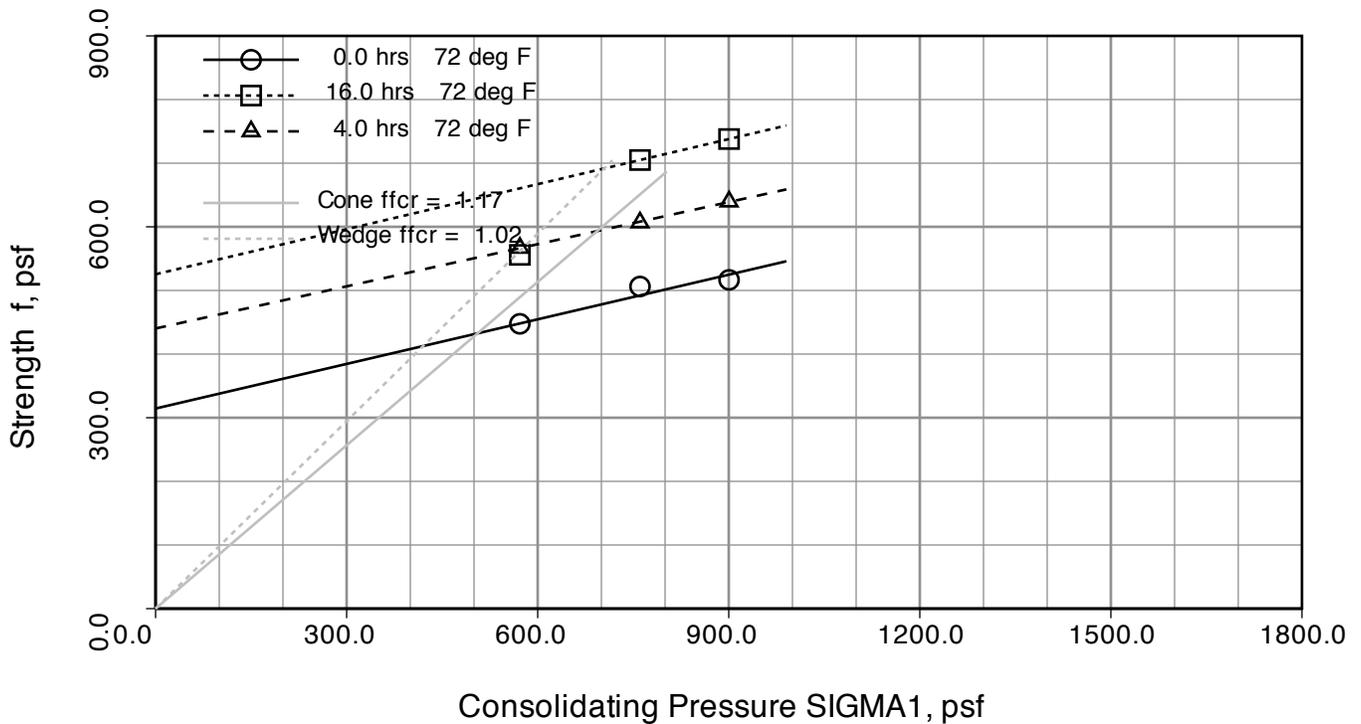
Chute Angles versus Impact Pressure
for Mild Carbon Steel Plate, Mill Finish



DELTA & PHI RELATIONS



FLOW FUNCTION(S)



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

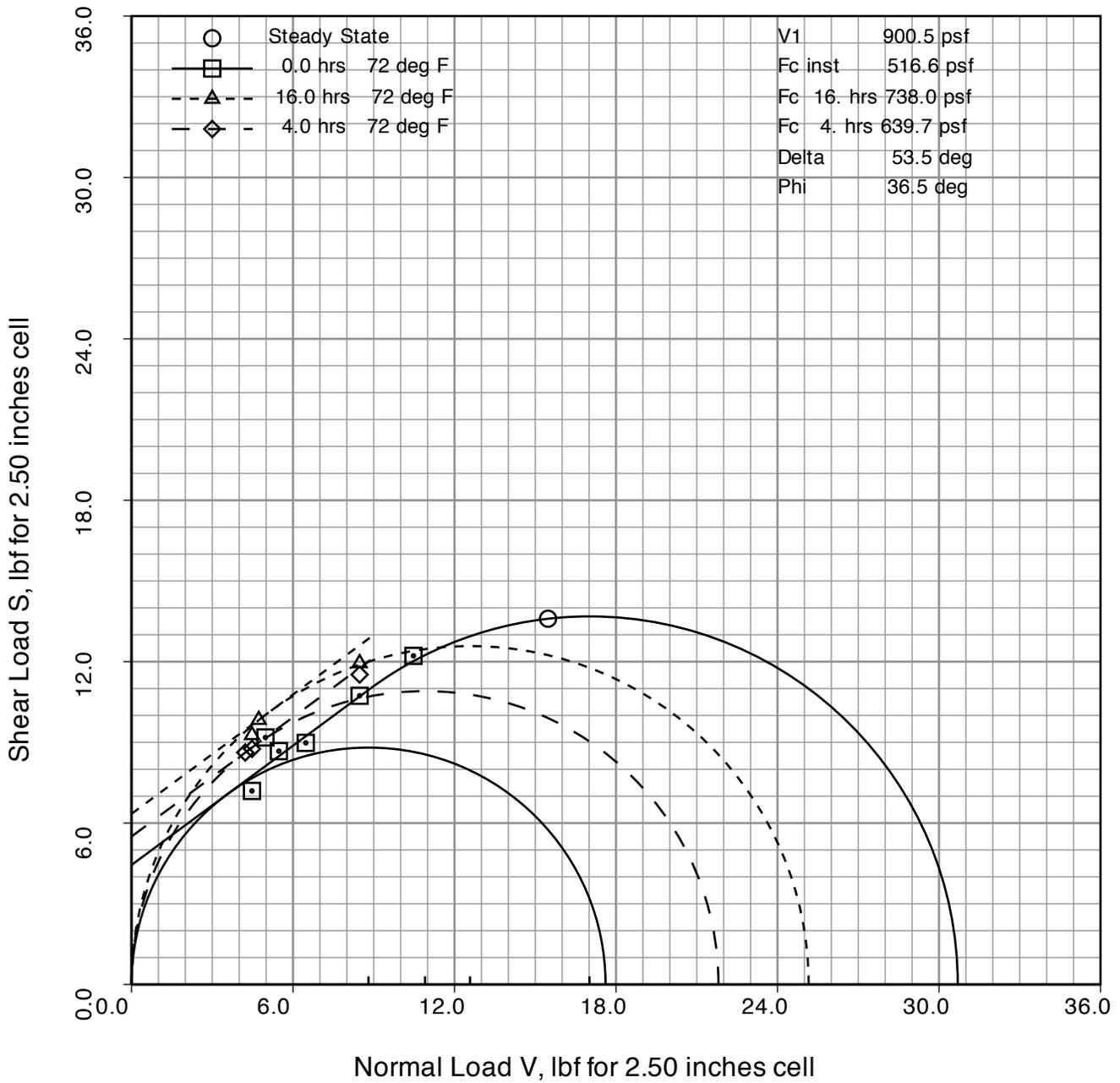
CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

YIELD LOCUS



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

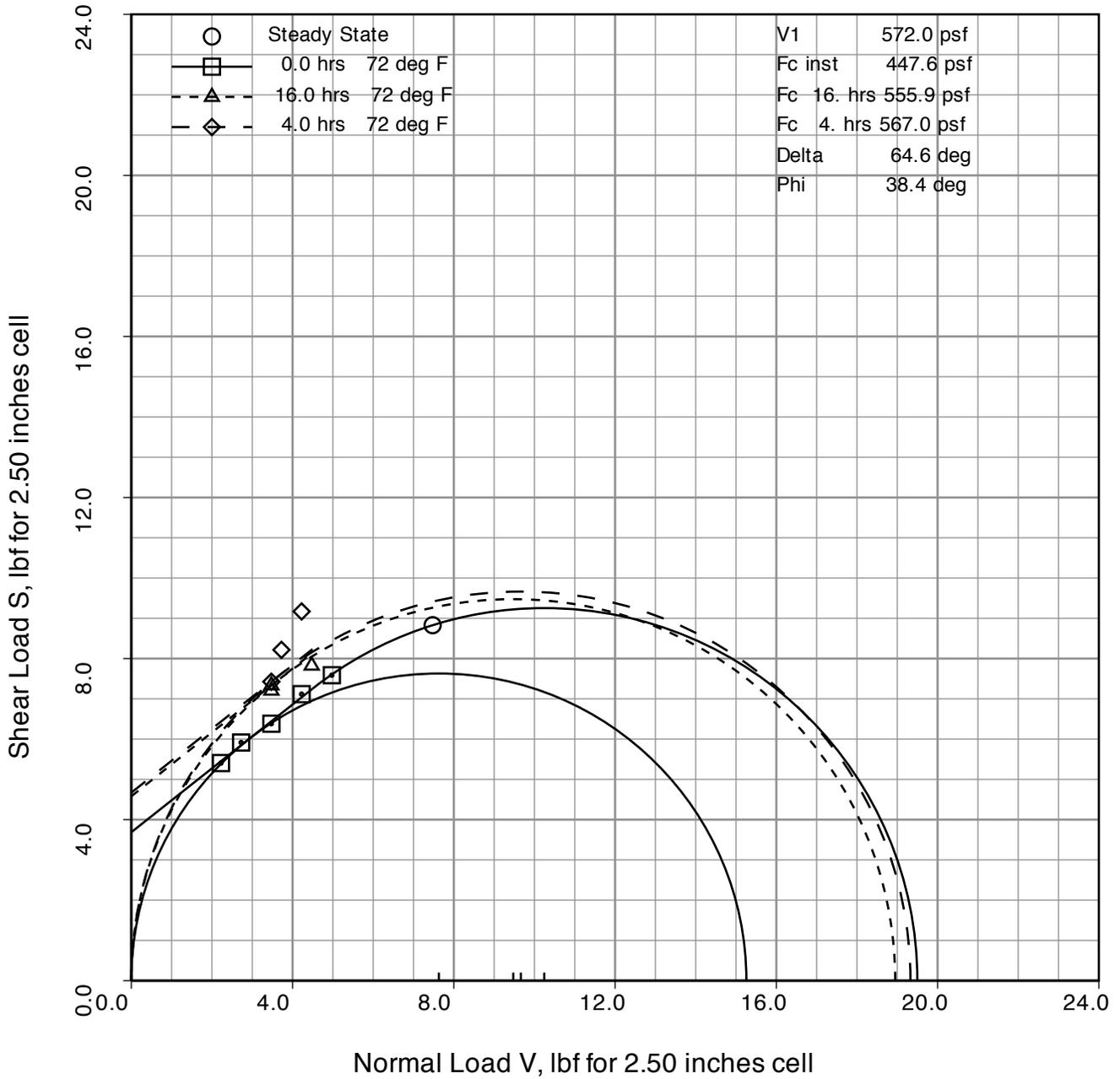
CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

YIELD LOCUS



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

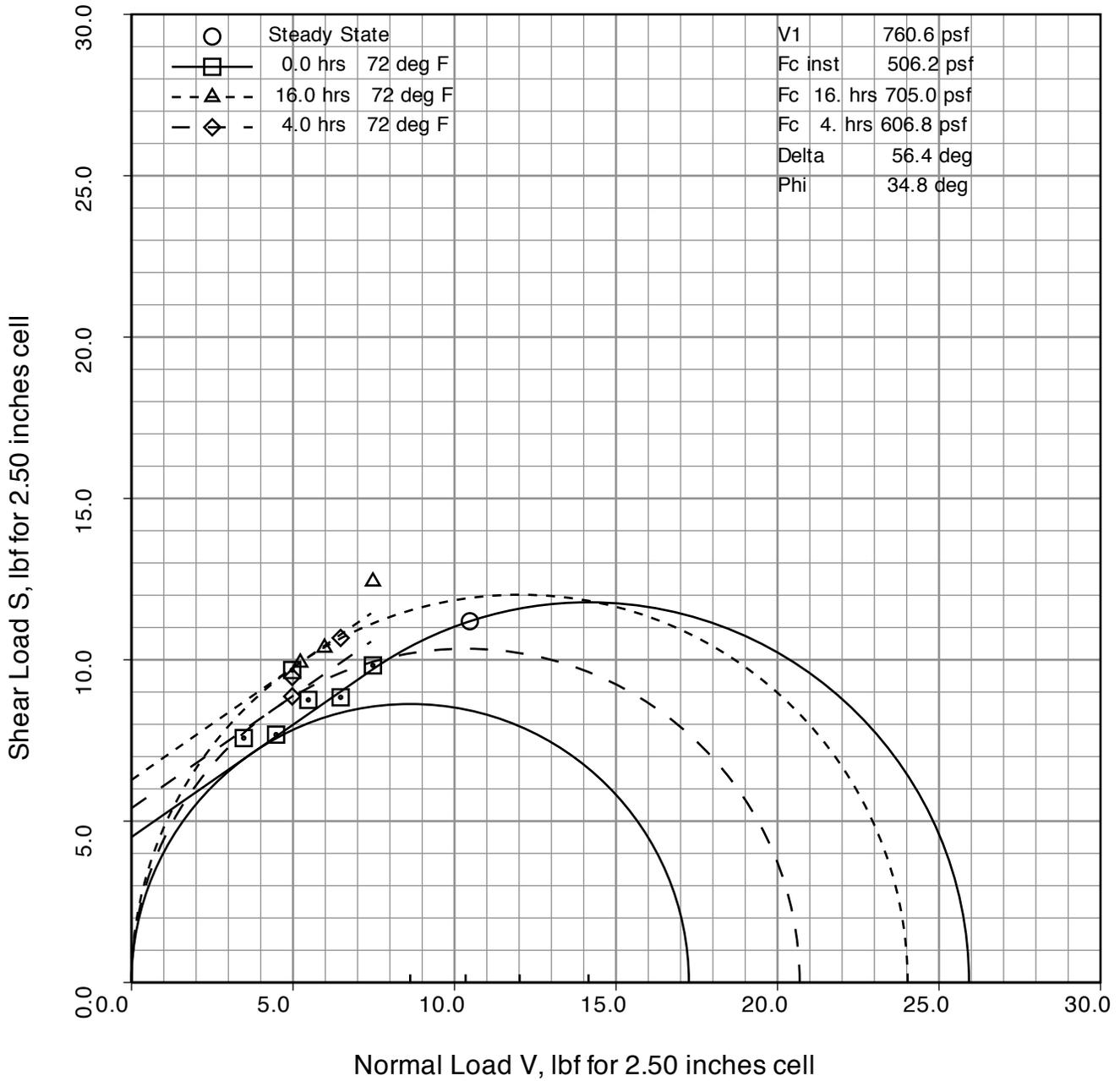
CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

YIELD LOCUS



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

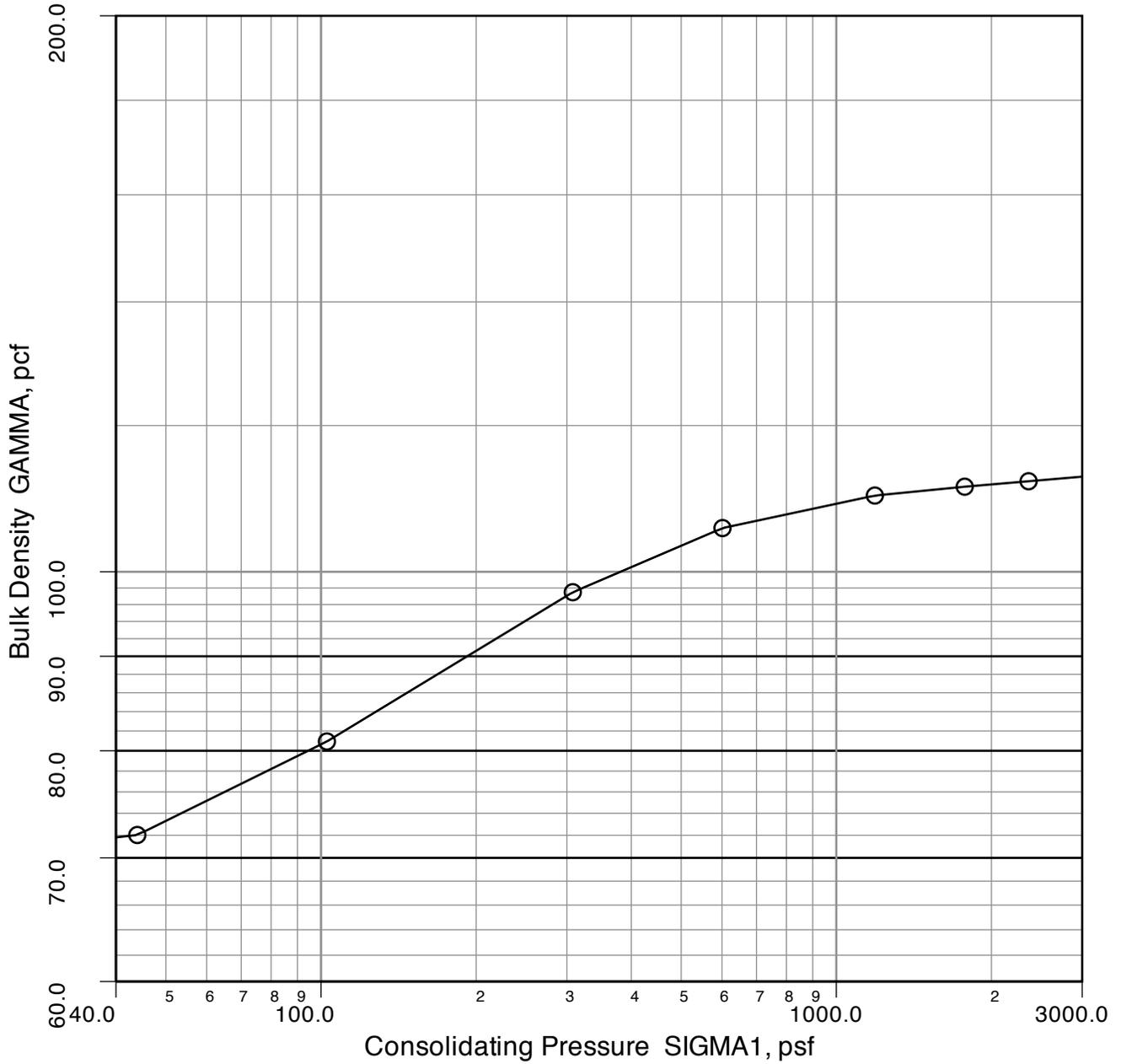
CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

BULK DENSITY VS. CONSOLIDATING PRESSURE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

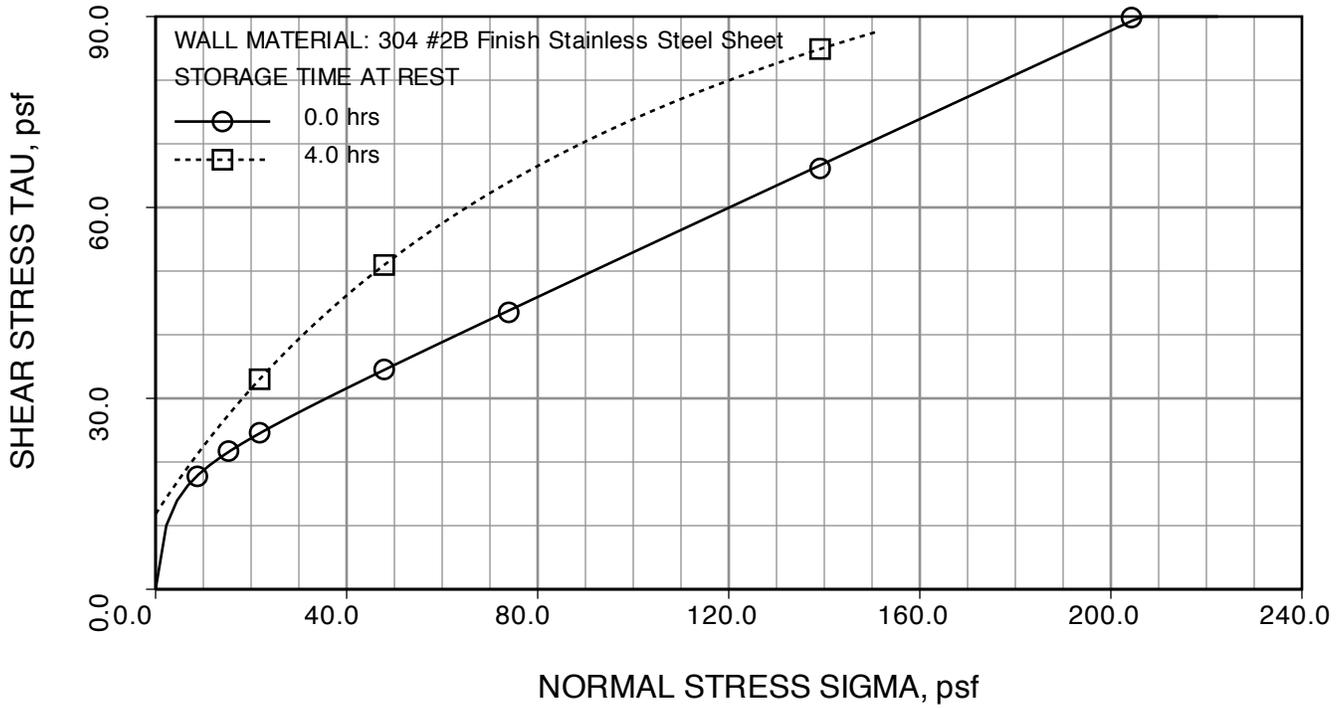
CREATE: 6/03/27

JOB#: 10057

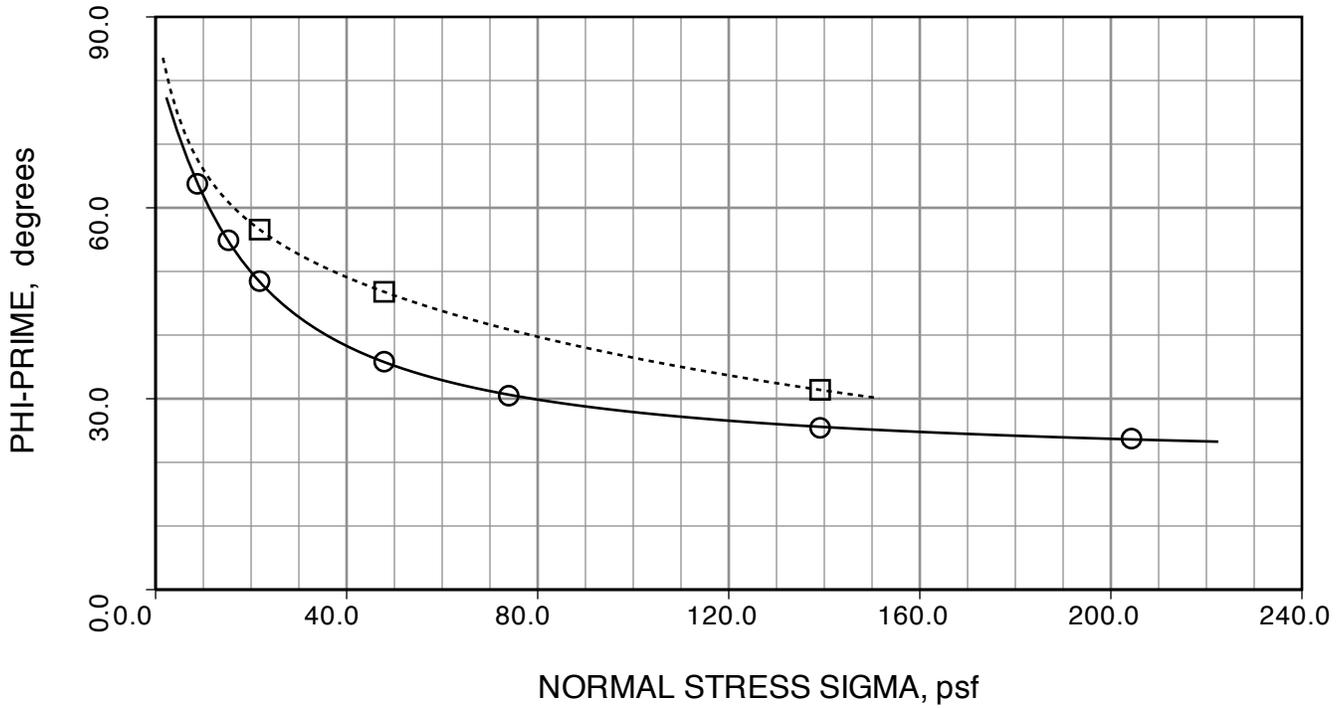
RUN: 6/04/06

ID#: 24543

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

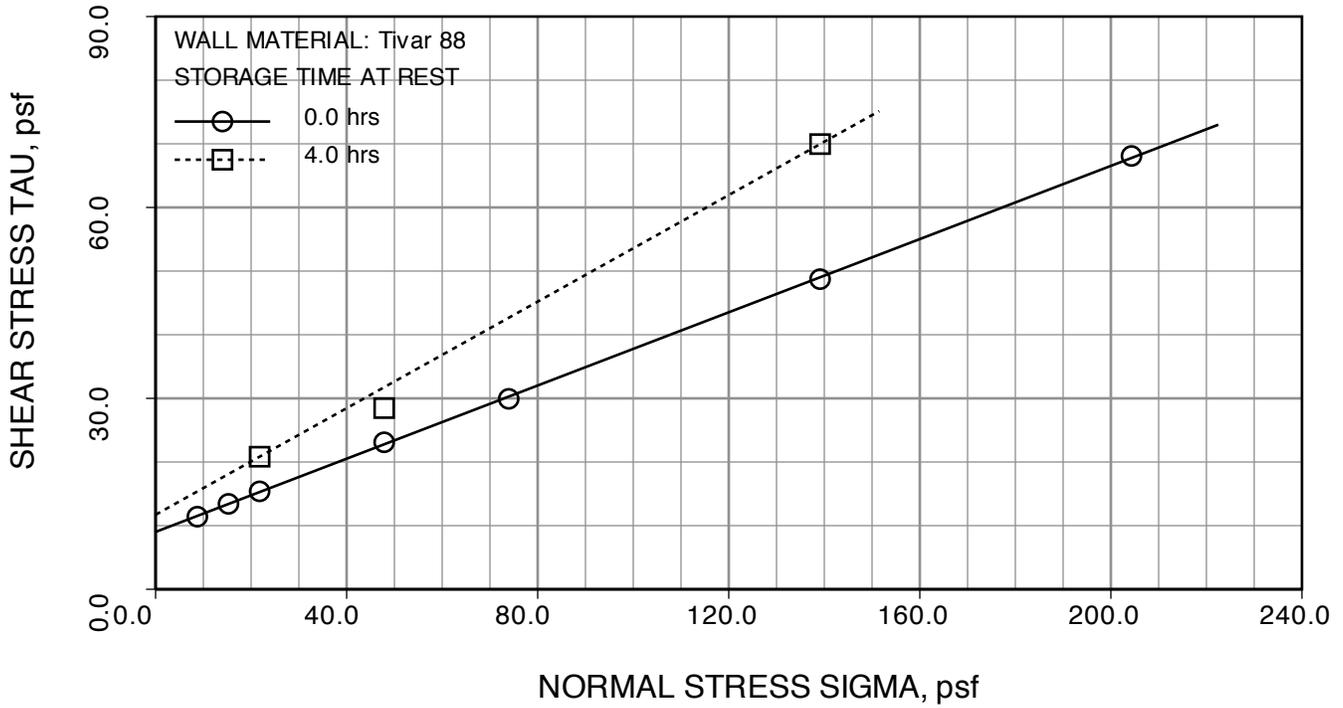
CREATE: 6/03/27

JOB#: 10057

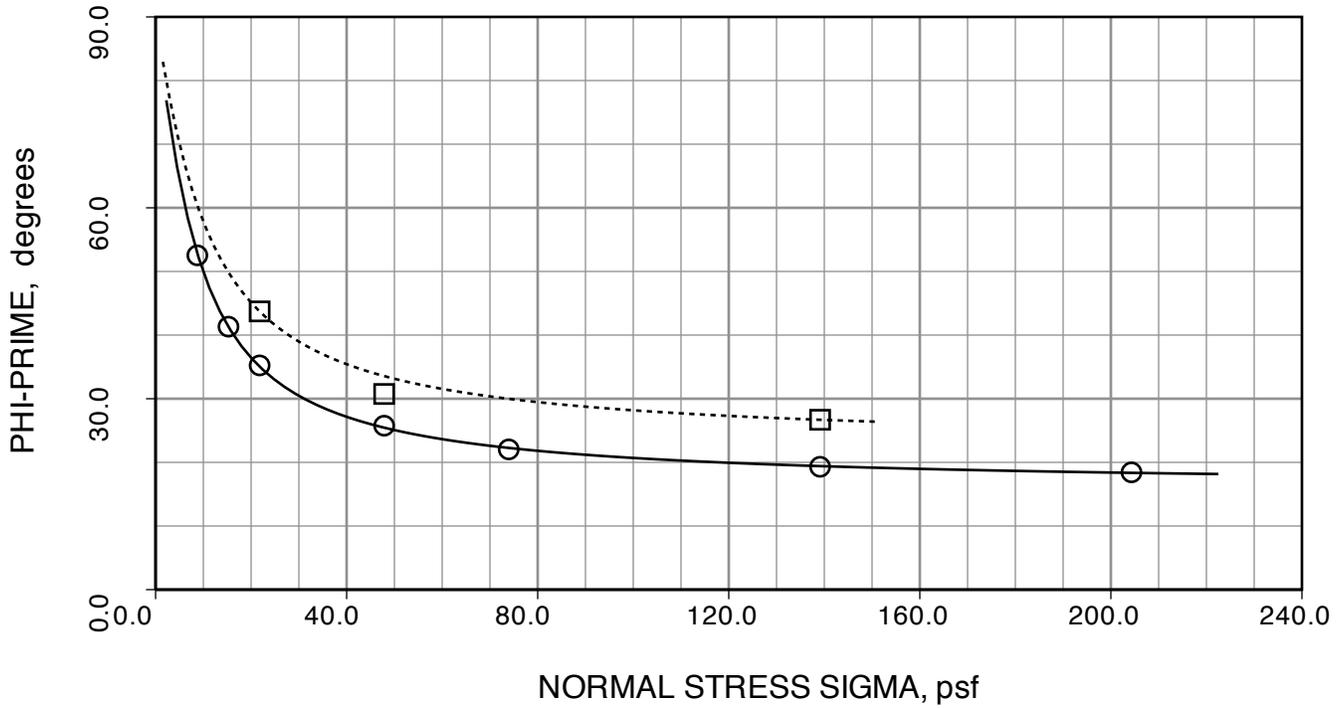
RUN: 6/04/06

ID#: 24543

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

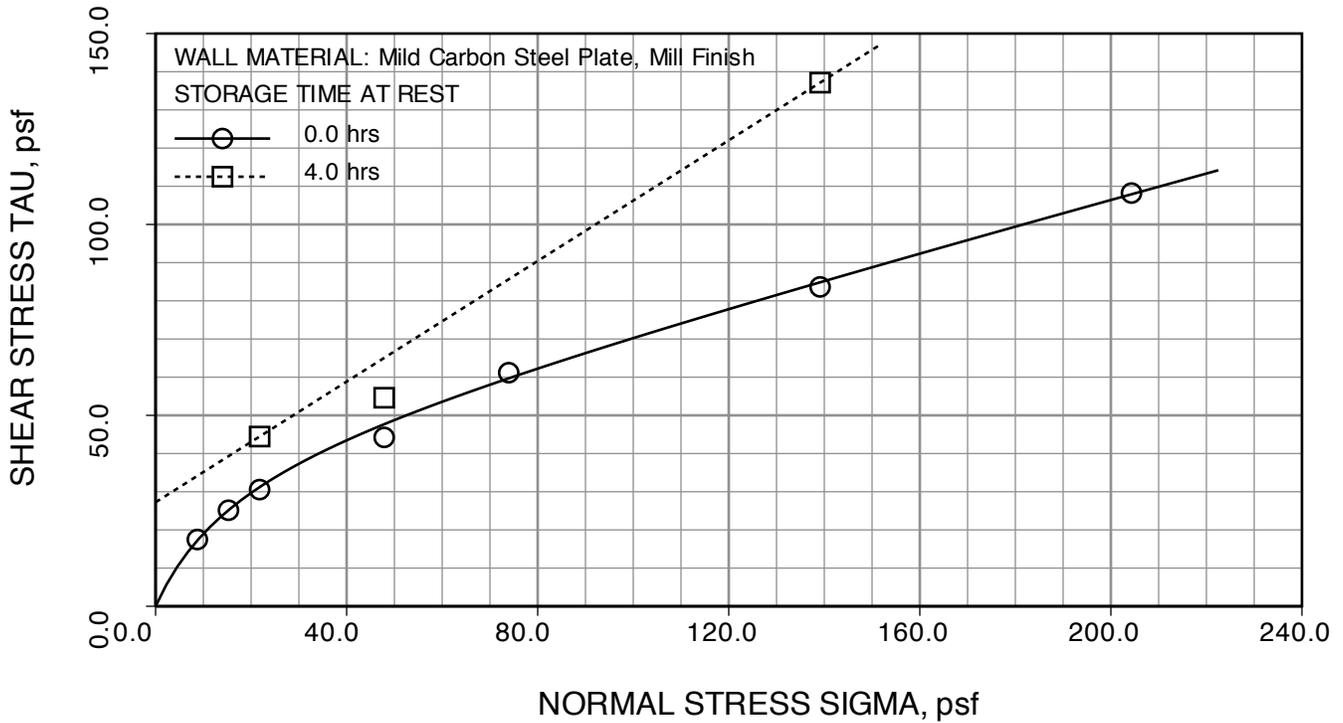
CREATE: 6/03/27

JOB#: 10057

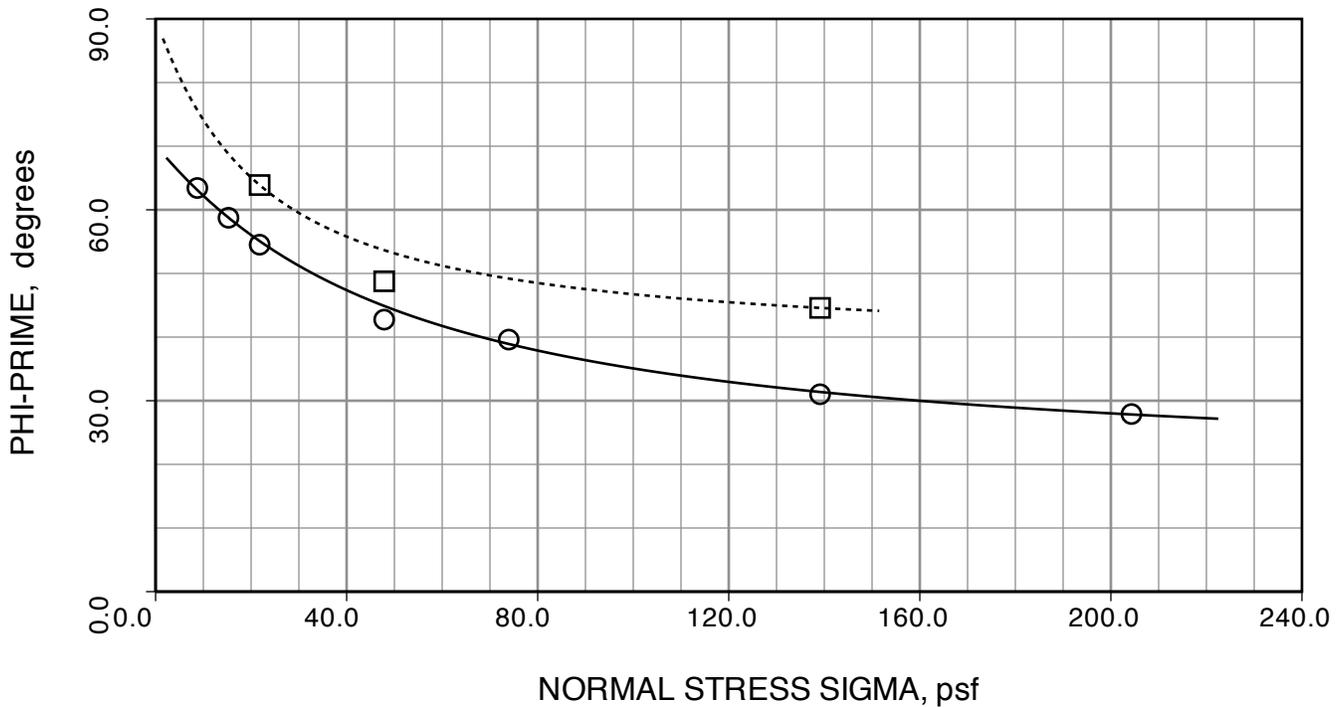
RUN: 6/04/06

ID#: 24543

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

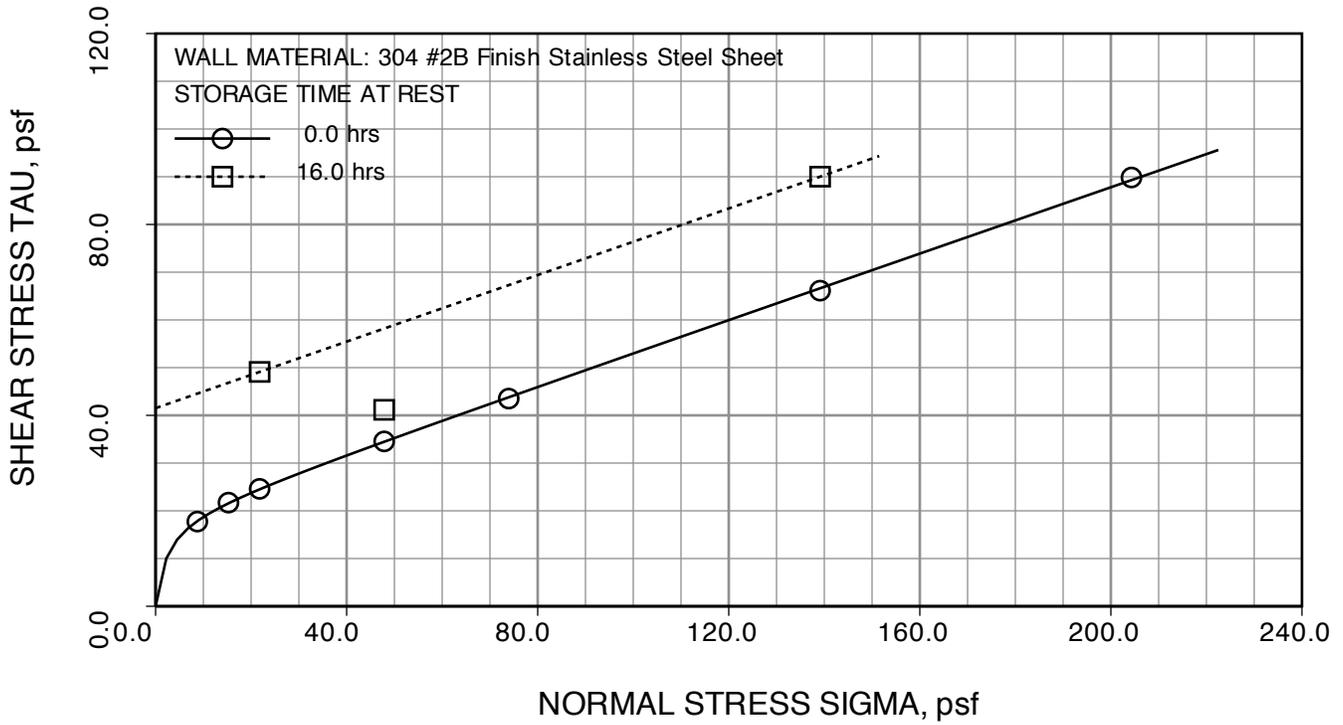
CREATE: 6/03/27

JOB#: 10057

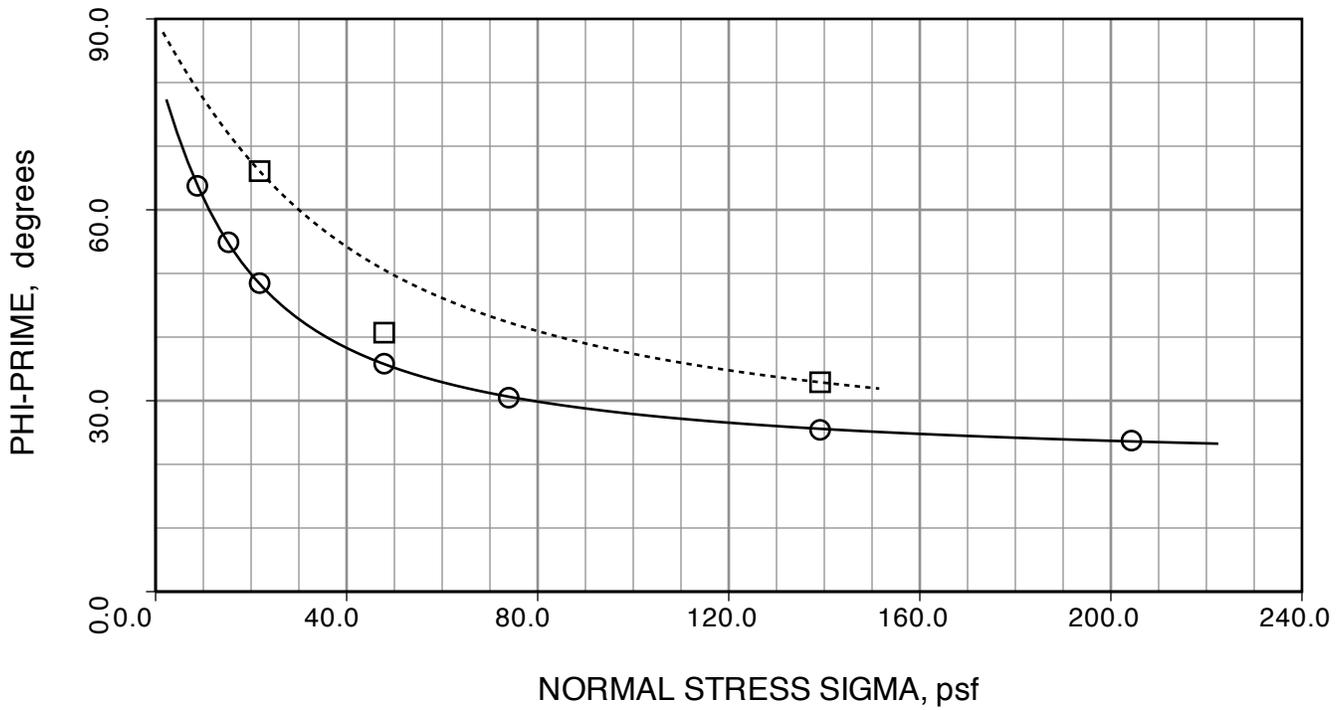
RUN: 6/04/06

ID#: 24543

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

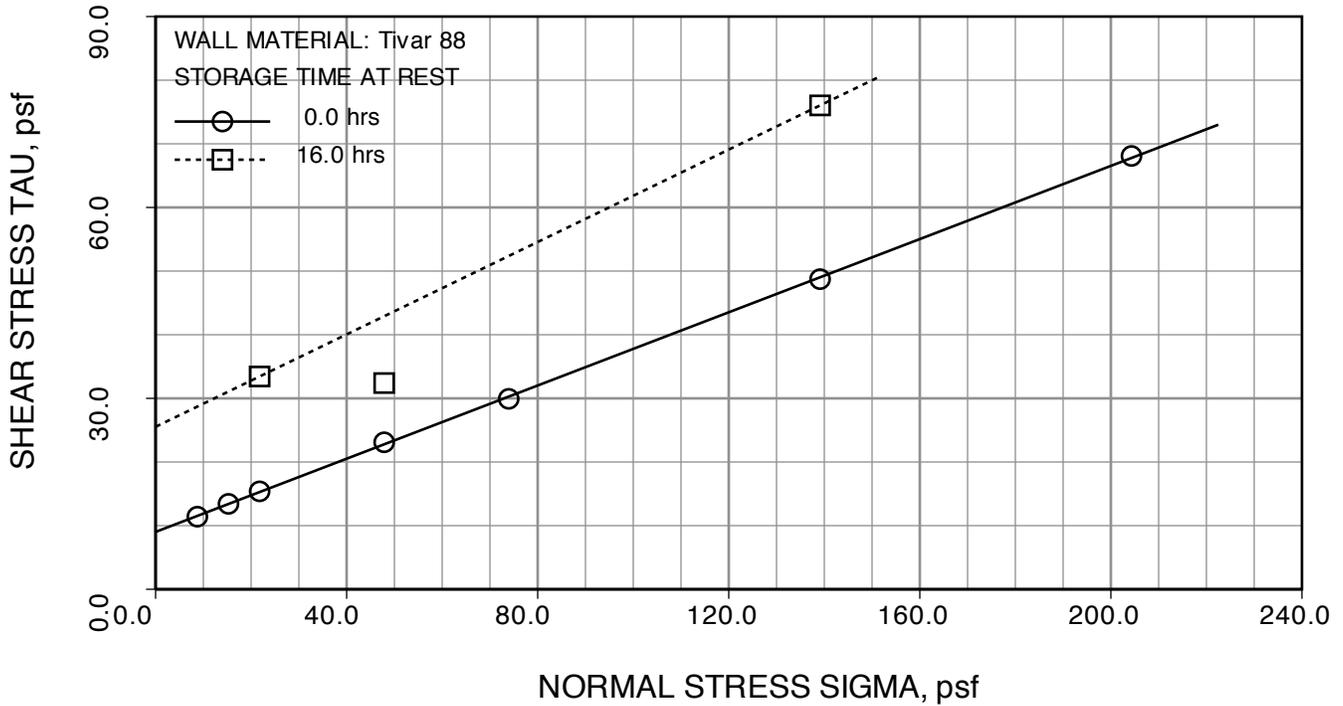
CREATE: 6/03/27

JOB#: 10057

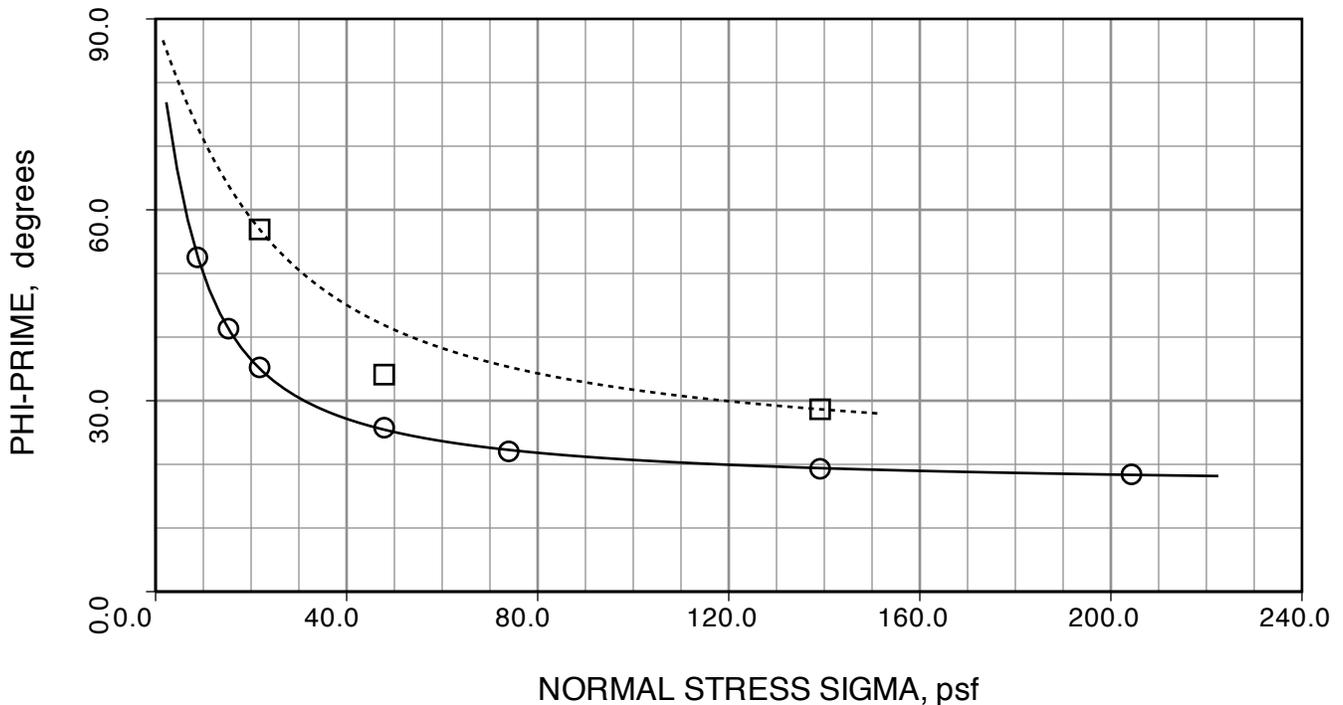
RUN: 6/04/06

ID#: 24543

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

TEMPERATURE: 72 deg F

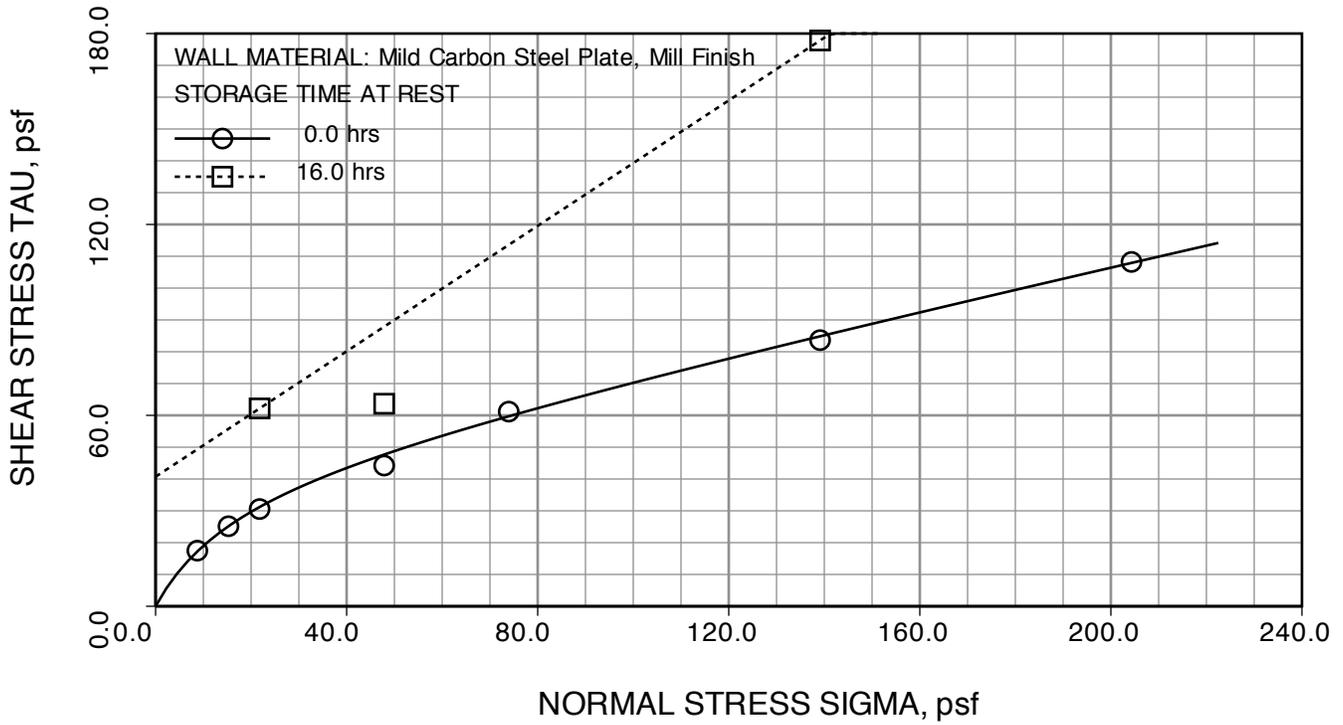
CREATE: 6/03/27

JOB#: 10057

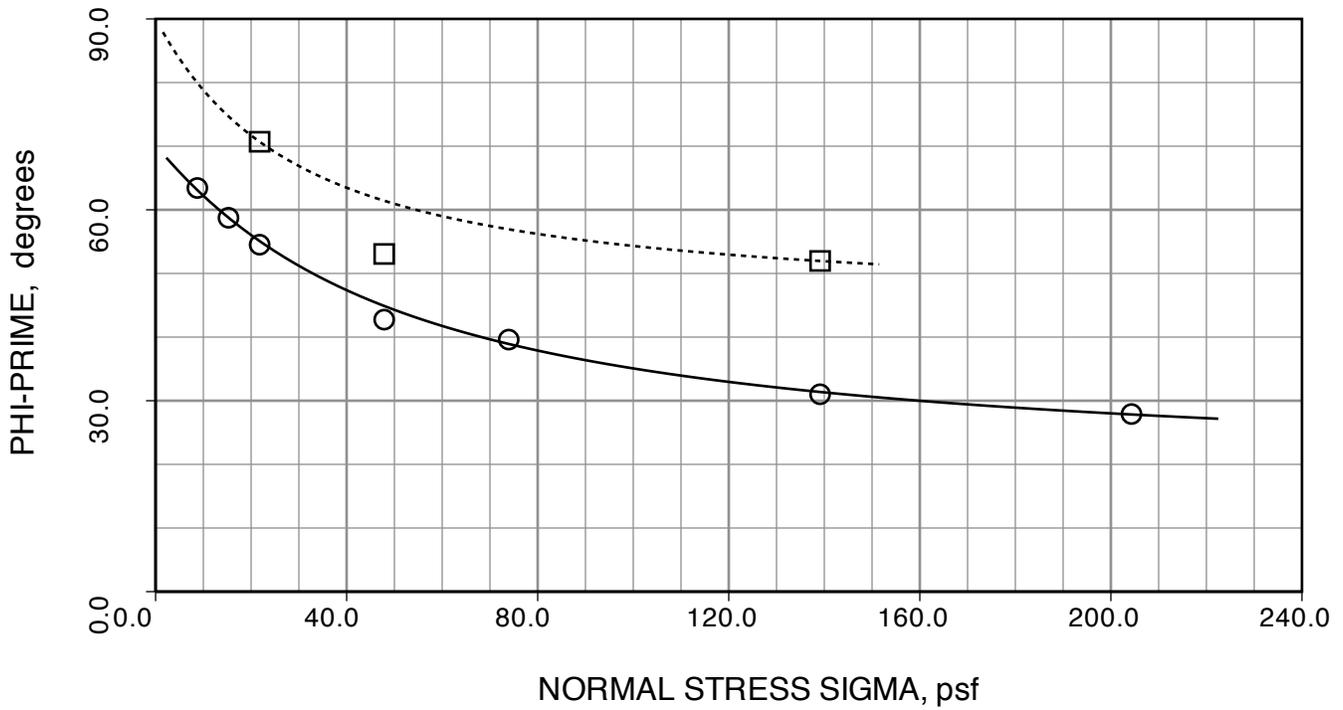
RUN: 6/04/06

ID#: 24543

WALL YIELD LOCUS



WALL FRICTION ANGLE



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

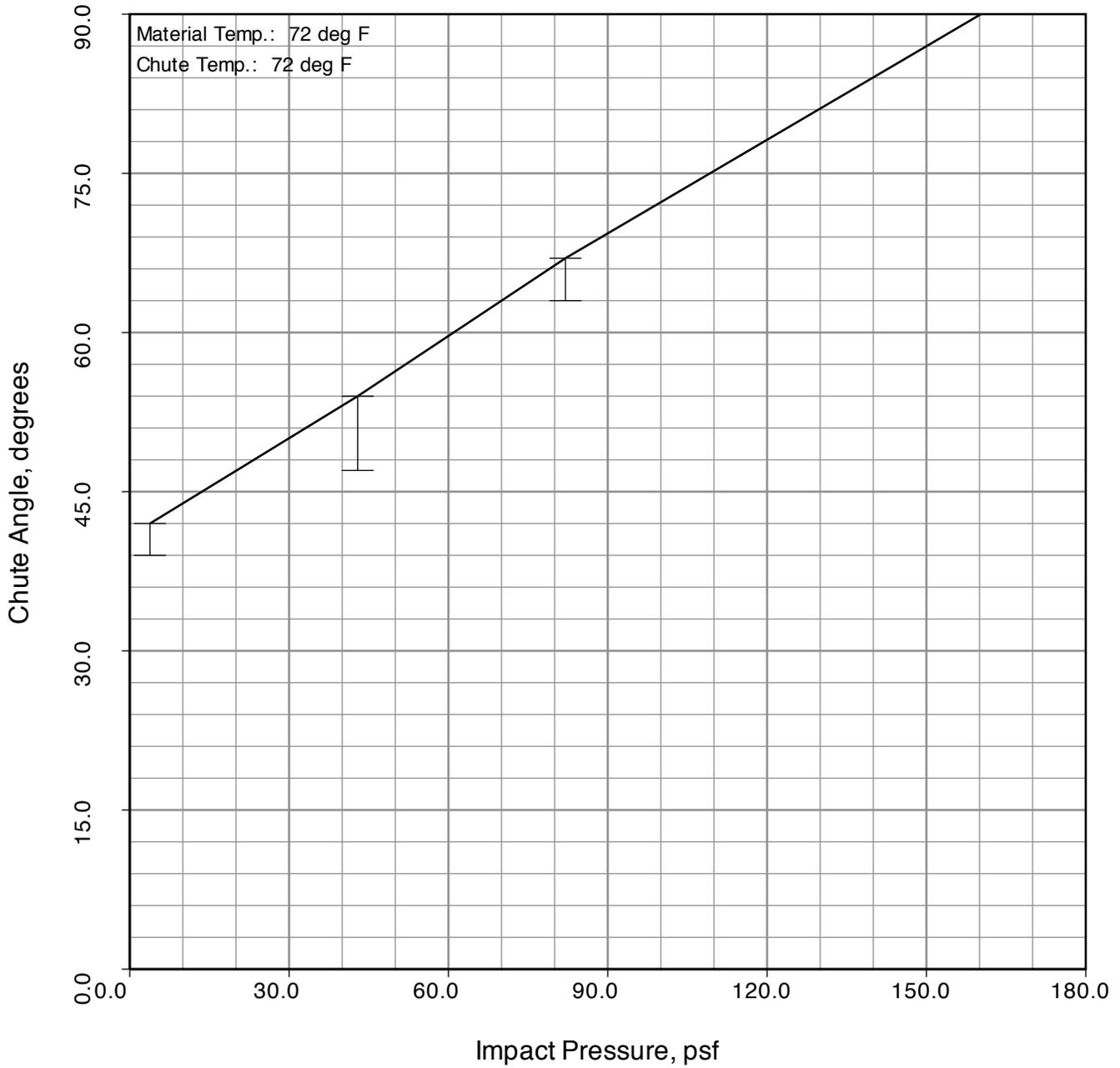
CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

Chute Angles versus Impact Pressure
for 304 #2B Finish Stainless Steel Sheet



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

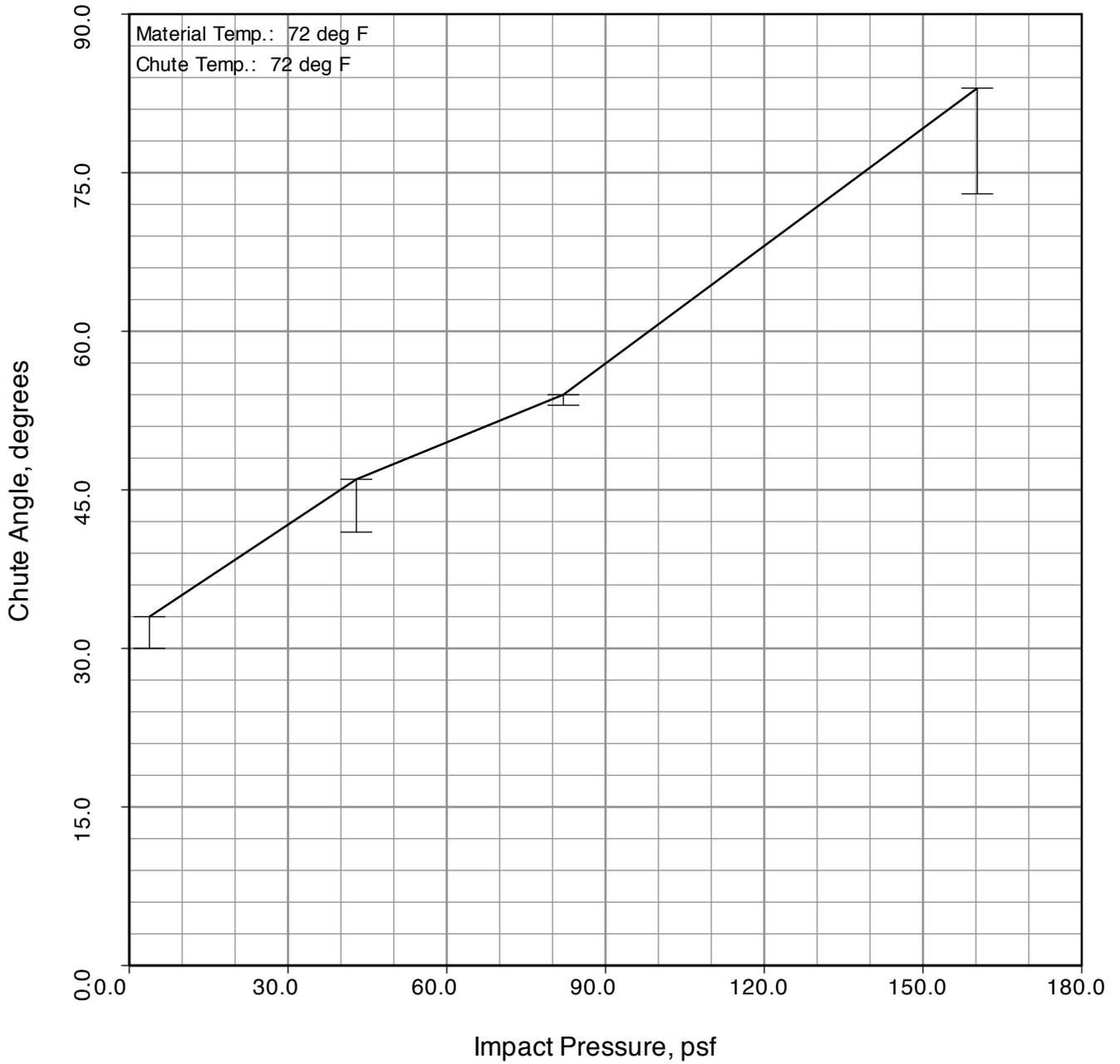
CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

**Chute Angles versus Impact Pressure
for Tivar 88**



BULK MATERIAL: 718 Moab Tailings 3-5'

PARTICLE SIZE: As Rec'd

MOISTURE % WT: As Rec'd

CREATE: 6/03/27

RUN: 6/04/06

JOB#: 10057

ID#: 24543

Chute Angles versus Impact Pressure
for Mild Carbon Steel Plate, Mill Finish

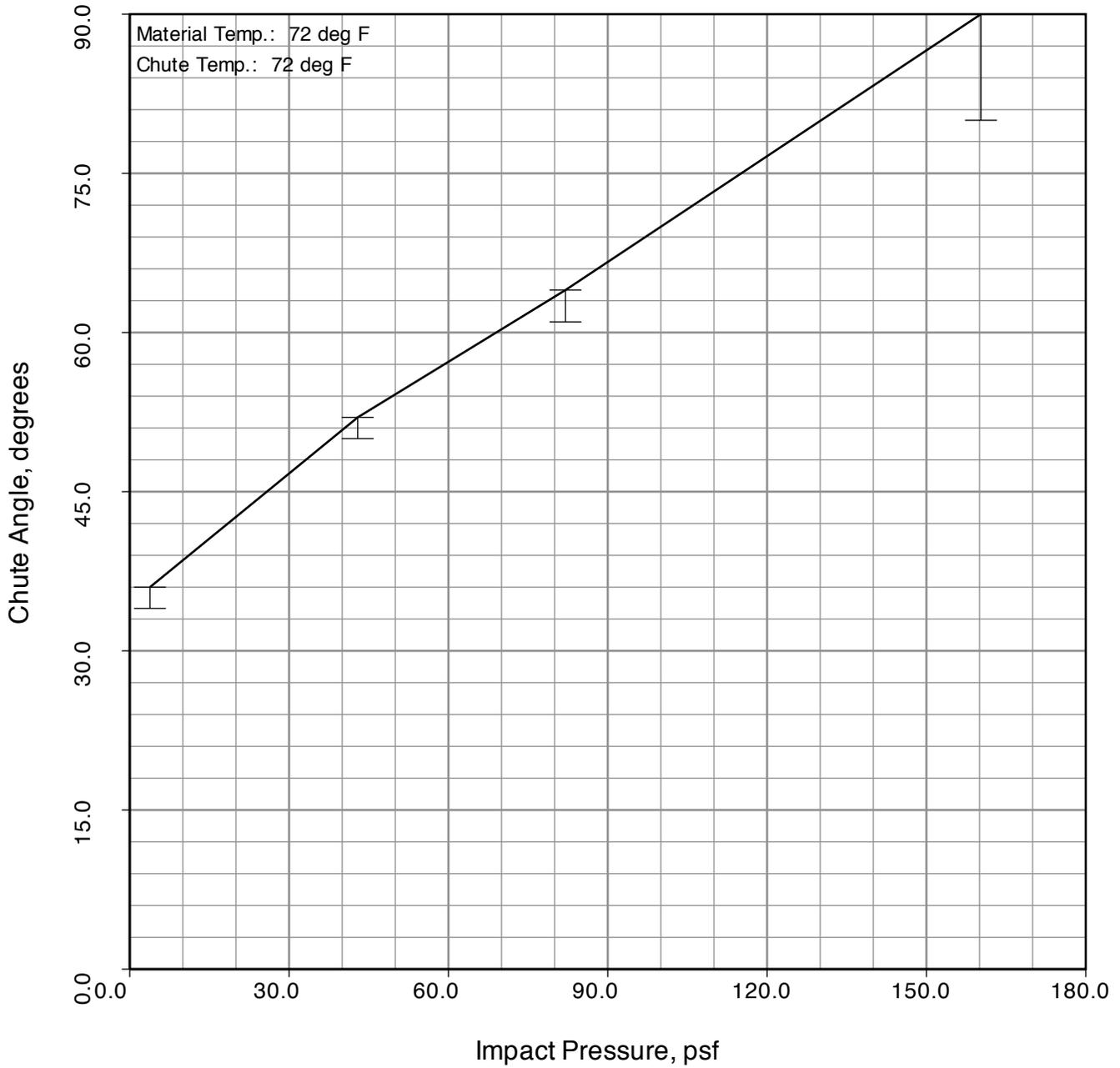


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SELECTION OF BIN AND FEEDER

Types of bins

A bin (silo, bunker) generally consists of a vertical cylinder and a sloping, converging hopper.

The first step in the process of bin selection is to decide on the type of bin required. From the standpoint of flow, there are three types: mass flow, funnel flow, and expanded flow.

Mass flow bins

In a mass flow bin, the hopper is sufficiently steep and smooth to cause flow of all the solids without stagnant regions whenever any solids are withdrawn.

Mass flow bins, examples of which are shown in Figure A1, have certain advantages. Flow is uniform, and the feed density is practically independent of the head of solids in the bin. This frequently permits the use of volumetric feeders for feed rate control. Since stagnant regions are eliminated, low level indicators work reliably. Even though the solids may segregate at the point of charge into the bin, segregation of the discharge is minimized by the first-in-first-out flow sequence associated with mass flow. This flow sequence also ensures uniform residence time and deaeration of fine powders.

Mass flow bins are recommended when handling cohesive materials, powders, and materials which degrade with time, and when segregation needs to be minimized.

Ledges and protrusions are not permitted in a mass flow hopper. In addition, the outlet must be fully effective. If the hopper is equipped with a shut-off gate, the gate must not prevent flow of material along the hopper wall. If a feeder is used, it must draw material across the full outlet area. (See "Feeders" below)

Mass flow bins can be used for in-bin blending. Of particular benefit in this regard is Jenike & Johanson's patented BINSERT® system. This device controls the flow pattern of solids in a bin.

Funnel flow bins

Funnel flow occurs when the hopper is not sufficiently steep and smooth to force material to slide along the walls. It also occurs when the outlet of a mass flow bin is not fully effective. Examples of funnel flow bins are shown in Figure A2.

In a funnel flow bin, solids flow toward the outlet through a channel that forms within stagnant material. With non-free-flowing solids, this channel expands to a diameter that approximates the largest dimension of the outlet. When the outlet is fully effective, this dimension is the outlet's diameter if circular, or the diagonal if the outlet is square or rectangular. The channel will be stable if its diameter is less than the critical rathole diameter.

With free-flowing solids, the flow channel expands at an angle which depends on the effective angle of friction of the material. The resulting flow channel is generally circular with a diameter in excess of the outlet diameter or diagonal.

When the bin discharge rate is greater than the charge rate, the level of solids within the channel drops, causing layers to slough off the top of the stagnant mass and fall into the channel. This spasmodic behavior is detrimental with cohesive solids since the falling solid packs on impact,

thereby increasing the possibility of arching. With sufficient cohesion sloughing may cease, allowing the channel to empty out completely and form a stable rathole. Aerated solids charged into this empty rathole might overflow the feeder.

When a fluidized powder is charged directly into a funnel flow channel at a sufficiently high rate and is withdrawn at the same time, it has no chance to deaerate. It therefore remains fluidized in the channel and floods when exiting the bin. A rotary valve is often used under these conditions to contain the material, but a uniform flow rate cannot be ensured because flow into the valve is erratic.

In general funnel flow bins are suitable only for coarse, free-flowing or slightly cohesive, non-degrading solids when segregation is unimportant.

Converting funnel flow bins to mass flow can often be achieved with relatively little expense. One way to do this is to use the BINSERT® system referred to in the paragraph on blending above. Another way is to install a low friction liner.

Expanded flow bins

Examples of expanded flow bins are shown in Figure A3. The lower part of such a bin operates with flow along the hopper walls (similar to mass flow), while the upper part operates in funnel flow. The mass flow outlet usually requires a smaller feeder than would be the case for a funnel flow bin. The mass flow hopper section should expand the flow channel to a diagonal or diameter equal to or greater than the critical rathole diameter. This eliminates the likelihood of ratholing in the funnel flow section.

These bins are used for storage of large quantities of non-degrading solids. This design is also useful as a modification of existing funnel flow bins to correct erratic flow caused by arching, ratholing, or flooding.

This concept can be used with multiple outlets as shown in Figure A3 (B), where simultaneously flowing mass flow hoppers are placed close enough together to cause a combined flow channel larger than the critical rathole diameter.

With extremely free-flowing solids such as plastic pellets, cement clinker, and coarse sand, both funnel flow and expanded flow bins may pulsate. This is caused by the flow pattern suddenly switching from a steady state, central channel-type flow to a much more extensive secondary flow pattern that may extend to the bin walls. Such a condition may reduce segregation problems, but the shock loads imposed may seriously challenge the structural integrity of the bin.

Feeders

Feeders are used to control the rate of material discharge from a bin (hopper, silo, bunker) outlet. They must not be confused with conveyors, which simply transport material from one point to another. Common feeders include screws, belts, rotary vanes, rotary plows, rotary tables, vibrating pans, and vibrating louvers. The rate of material being discharged is most commonly controlled volumetrically from these feeders, i.e., the volume of material per unit time may be varied by changing feeder speed, amplitude, or frequency. Several of these feeders may also operate gravimetrically, i.e., the mass of material per unit time is measured and controlled.

Proper feeder selection depends on a number of factors based on the bin choice and feed requirements.

Two major objectives for efficient feeder design are uniform withdrawal of the material from the entire bin outlet area (i.e., fully effective outlet) and minimizing the material loads on the feeder, all

within the process requirements of flow rate and layout. In order to ensure that the outlet is fully effective, the choice of feeder must be based on the outlet size and shape. If the requirements of bin selection dictate that the outlet be slotted, the feeder must increase in capacity in the direction of feed to ensure a uniform draw of material across the entire outlet. The choice of feeders is generally limited to either a belt or a screw. If the feeder's capacity does not increase properly, the feeder will tend to draw material from either the front or back of the slot, resulting in a high velocity flow channel having a diameter only one to two times the width of the slot. This becomes critical when feeding powders, since the powder may remain fluidized within this channel and flood on exiting the bin.

To limit high initial loads and starting torque caused by differential settlement between the hopper and the feeder, it is essential that the feeder be either suspended from the bin itself or supported on a flexible frame so as to readily deflect with the bin as solids are added to it.

Detailed feeder selection guidelines are explained in technical papers available from Jenike & Johanson, several of which are listed in the Technical Papers Reference at the end of this Appendix.

DISCUSSION OF TEST REPORT DATA

In the discussion that follows, each section of the test report is explained in general terms. Please refer to Figures A1, A2, and A3, where many of the symbols are shown. The symbols and other terms used in the text are explained in the Glossary of Terms and Symbols on pages A13 to A15. The concepts of gravity flow of solids and examples of application of solids flow data are described in technical papers available from Jenike & Johanson. (See the Technical Papers Reference at the end of this Appendix).

Moisture

Unless otherwise noted, moisture values quoted in this report have been determined by preparing three samples, approximately 15g each. If the material contains coarse particles, each sample was first screened to -60 mesh. The samples were then dried at 107°C for two hours in a forced convection oven. The three values of loss in weight of each sample divided by its original weight were averaged and denoted as the sample's moisture.

Section I - Bin dimensions for dependable flow

This section specifies the bin outlet dimensions necessary for dependable flow in both mass flow and funnel flow bins. These dimensions have been calculated on the basis of the frictional and cohesive properties of the solid given in a subsequent part of the report. In all cases, it is assumed that flow takes place only under the action of gravity, i.e., without internal or external assistance.

In general these dimensions are a function of the time the solid remains in storage at rest; its moisture content, temperature, and particle size; and overpressure, if any, that is applied to it during storage. The P-FACTORS given in the table are ratios of applied compaction pressure to that pressure resulting from gravity flow only. If there are no overpressures present, the critical dimensions for P-FACTOR = 1.0 should be used. If the P-FACTOR is greater than 1.0, it is assumed that overpressures have been exerted on the solid during storage, but are removed when the solid is required to flow. See pages A6 to A8 for calculation of P-FACTORS. If overpressures are applied during discharge, additional considerations are required; contact a Jenike & Johanson engineer to discuss your specific application.

When considering the effect of overpressure, which acts on a solid during time of storage at rest, it is not necessary that the overpressure act during the entire time at rest. Soon after an overpressure has been applied, a solid reaches the maximum densification associated with the overpressure.

Hence, the critical outlet dimensions will be essentially the same whether the overpressure acts for a short time or continuously during the entire time at rest.

Mass flow bins have hopper walls that are smooth enough and steep enough to cause flow along them; hence, stable channels within the material (ratholes) do not develop. Only two dimensions, both of which are shown in Figure A1, are specified: BC, the minimum outlet diameter for a conical hopper; and BP, the minimum width for a slotted or oval outlet. The length of the slot or oval should be at least three times its width or the end walls must be vertical and smooth for BP to apply. These outlet dimensions are recommended to prevent cohesive arching. Particle interlocking should also be considered.

A funnel flow bin is created whenever the hopper walls are not steep enough and smooth enough to cause flow along them. Slotted outlets are recommended for these bins unless the material is quite free flowing. To prevent stable arches from forming, the width of the slot must be at least equal to BF. In a funnel flow bin the solid is held up at the walls and flows only within a circular channel whose diameter is approximately equal to the diameter or length of the effective outlet. If this flow channel diameter is less than the critical rathole diameter DF given in the report, a stable rathole is likely to form, and the live capacity of the bin will be essentially only that material which is in the flow channel above the outlet. To prevent stable ratholes from forming, funnel flow bins should be designed with slotted outlets of length at least as long as DF.

In general, DF is proportional to the consolidating pressure imposed on the solid during filling of the bin. Hence, in the upper regions of a bin where pressures are low, the critical rathole diameter DF is small and the flow channel diameter may exceed DF. This causes the rathole to be unstable at this point, allowing the material to collapse into the stable rathole below. A partial emptying of the bin will result.

Calculation of effective head EH

The critical rathole diameter DF is a function of the major consolidating pressure which acts on the solids in the bin. It is convenient to express this pressure in terms of EH, the effective consolidating head of solid in the bin, as follows:

$$\begin{aligned} EH &= [R/(\mu k)] [1 - e^{-\mu k H/R}] \\ \text{or} \\ EH &= 2R \end{aligned} \tag{1}$$

whichever is larger. The parameters are:

R = hydraulic radius of the cylindrical portion of the bin, i.e., ratio of cross sectional area to circumference
R = D/4 for a circular cylinder of diameter D or a square cylinder of side D
R = W/2 for a long rectangular cylinder of width W

μ = tan (PHI-PRIME), coefficient of friction between the stored solid and the cylinder walls (see Section III)

k = ratio of horizontal to vertical solids pressure. A value of 0.4 is usually acceptable within cylinders

H = height of the cylindrical portion of a bin

When the feeder is properly designed for uniform flow and when convergence of the hopper extends to the feeder, the effective head EH of solid on the feeder during flow in a mass flow bin is approximately

$$\begin{aligned} \text{EH} &= \text{BP for a transition mass flow hopper} \\ \text{EH} &= \text{BC}/2 \text{ for a conical mass flow hopper} \end{aligned} \quad (2)$$

See page A5 for definitions of BP and BC.

Initial loads may be several times these values.

Calculation of P-FACTORS

The magnitude of the overpressure factor can be estimated for vibration, impact during charging into the bin, external loading, and fluid flow loading as follows (note these are valid only if applied prior to flow):

Vibration. Vibration has two effects: while it tends to break arches that obstruct flow, it also packs the solid in stagnant regions, thereby giving it greater strength. In order to allow for this packing, the recommended outlet dimensions at zero time at rest for a P-FACTOR of 1.5 may be used as an approximation when calculating critical arching dimensions for use with vibrating equipment.

Vibrators are suitable for materials which are free flowing under conditions of continuous flow but cake and gain strength when stored at rest for hours or days. Hoppers for these materials should be equipped with pads for mounting external vibrators. Vibrators should be used only to initiate flow and should be turned off once flow has started.

Fine powders and wet materials tend to pack severely when vibrated; hence, vibrating equipment is generally not recommended for them.

$$\begin{aligned} \text{P-FACTOR} &= (1 + a_z/g) \\ \text{or} \\ \text{P-FACTOR} &= a_y/g \end{aligned} \quad (3)$$

whichever is larger, where:

- a_z = vertical upward component of acceleration imposed on the solid
- a_y = horizontal component of acceleration imposed on the solid
- g = gravitational acceleration constant

Impact pressure from fall into a bin. A coarse material compacts as it is charged into a bin, under the impact of the falling particles. When the material contains fines and the impact area is close to the outlet, the impact P-FACTOR should be used in the design.

$$\text{P-FACTOR} = (1 + m) [w/(A B \text{ GAMMA})] \sqrt{2h/g} \quad (4)$$

where:

- w = weight flow rate into the bin
- h = height of fall
- m = 0 for a long rectangular outlet
- m = 1 for a circular or square outlet

- A = area impacted by the falling stream of solids
 B = outlet size or bin dimensions in the region of impact, i.e., the diameter in a conical hopper or the width in a wedge shaped or transition hopper
 GAMMA = bulk density of solid

External loading. If the solid has been compacted by an external load F (such as the weight of a tractor passing over an outside stockpile), the overpressure factor at the point of application is given by

$$P\text{-FACTOR} = (1 + m) F / (A B \text{ GAMMA}) \quad (5)$$

where:

A = area of load application

Liquid or gas flow loading. If the solid has been subjected during storage to fluid or gas flow such as may have been imposed by an air blaster, draining of a saturated solid or the flow of air or gas during drying or chemical processing, the overpressure factor is given by

$$P\text{-FACTOR} = 1 + (dp/dz) / (\text{GAMMA}) \quad (6)$$

where:

dp/dz = the (vertical) liquid or gas pressure gradient at the bin outlet where z is positive upward.

Limits on bin sizes

The bin dimensions in part A of this Section I apply to bins of unlimited maximum size. However, some materials will compact in large bins, causing large stable arches in the upper part of the hopper while the lower portion may discharge without a problem. This can lead to a very dangerous condition when a large arch is broken high in the hopper. The impact of the falling material may cause structural damage to the bin and possibly tear the hopper from the vertical bin section. If the material is capable of this type of behavior, an additional part B is included which gives the maximum allowable mass flow bin and hopper dimensions.

Often the upper limits on bin size occur only for compaction with time or for significant overpressure conditions. If this is the case, the bin can be designed for an unlimited size, provided the critical time and overpressure values are not exceeded during the bin operation.

Section II - Bulk density

The bulk density GAMMA of a material is used in bin load and capacity calculations. Values of bulk density of the sample tested are given in Section II as a function of the effective head of solid EH and the major principal consolidating pressure SIGMA1. The relationship is:

$$\text{SIGMA1} = \text{EH} \text{ GAMMA} \quad (7)$$

Within the cylindrical part of a bin, the effective consolidating head EH is given by eq. (1). At the outlet of a mass flow bin, the head is given by eq. (2).

Note that if the sample tested is the fine fraction of a material having a wide range in particle size, inclusion of the coarser particles will usually increase the bulk densities above those given in this section.

Bulk density values have been computed from measured compressibility parameters of the material, which are also given in Section II. In general, all materials have a minimum density GAMMA MINIMUM without fluidization. The relationship between bulk density and consolidating pressure applies only when densities are greater than GAMMA MINIMUM.

Section III - Maximum hopper angles for mass flow

A solid sliding on a bin wall encounters frictional resistance proportional to the tangent of the wall friction angle PHI-PRIME. This angle generally depends not only on the roughness of the wall but also on the pressure that the solid exerts on the wall. For many hard wall surfaces, the friction angle decreases as the solids contact pressure increases. This pressure, which varies with position in the bin, is usually lowest at the outlet; therefore, the hopper angle required is often dictated by the outlet size selected.

THETA-C and THETA-P are the recommended maximum hopper wall angles, measured from the vertical, for conical and transition mass flow hoppers, respectively. See Figure A1. These values have been calculated from the friction tests (wall yield loci) included at the end of the report and are tabulated for a series of widths of oval hoppers and diameters of conical hoppers.

To minimize headroom, consider changing the slope of the hopper wall as a function of position. For example, if a conical hopper is to be designed with an outlet diameter of 1ft. and the recommended THETA-C is 14° at 1ft. diameter and 23° at 2ft. and larger diameters, use two conical sections. In the lower section where the diameter varies from 1ft. to 2ft., use a hopper angle of 14°. Above the 2ft. diameter, use a hopper angle of 23°.

Often, both continuous flow and time friction tests are run on a material. If the solid adheres to the wall with time, the time test results will indicate an increase in friction angles. To overcome this time effect, the hopper walls should be made steeper, as recommended, or other means – such as vibration of the bin walls – should be provided to initiate flow.

Section IV - Critical solids flow rate

Coarse bulk solids

The maximum rate Q at which a coarse solid (say, 95% plus 1/4in.) flows out of a mass flow hopper is practically independent of the head of solid and is approximately given by

$$Q = (A \text{ GAMMA}) \sqrt{Bg/[2(1 + m)\tan(\text{THETA})]} \quad (8)$$

where:

- A = area of the outlet
- B = diameter or width of the outlet
- THETA = planar hopper wall angle for rectangular or oval outlets, or
= conical hopper wall angle for circular outlets

Fine bulk solids

Predicting the flow rate of fine solids from mass flow bins is more complicated because their outflow is critically affected by the amount of air entrained in the solid.

Two limiting cases may occur: first, the bin may be charged and discharged at such a rapid rate that a large amount of air is entrained within the solid. As a result the solid may flood uncontrollably from the outlet independent of feeder speeds. The prediction of this critical flooding condition requires an extensive two-phase flow calculation using a Jenike & Johanson proprietary computer program and is not a part of this Flow Properties Test Report.

Second, the bin may be filled intermittently, with sufficient retention time before discharging so that the powder is deaerated. As a result there may be a deficiency of air as the solids expand upon discharging. This generally causes a critical flow rate at the outlet which is tabulated in this section as a function of effective head of solid in the bin. Above this critical rate, flow will be non-steady.

The critical rates are computed on the assumptions that there is no air in-flow or out-flow along the height of the bin, that air pressure at the outlet of the bin is the same as at the top of the bin, and that the feeder outlet is not sealed against air in-flow. Should the operating conditions deviate from these assumptions, a controlled rate different from the critical may be possible.

If the tabulated flow rates are lower than desired, it may be necessary to use an air permeation system to increase the rate; increase the outlet size; decrease the bin size; or limit the storage time to prevent deaeration of the solid. Jenike & Johanson can analyze the system and make recommendations.

If the specified flow rate from a bin is close to critical values, it is particularly important that the feeder withdraw uniformly across the entire outlet. If this is not done, localized limiting rate effects may occur at the outlet, especially at the ends of a slotted outlet. This may result in pulsating flow from the bin, the development of fast flowing columns, and an uncontrolled rate of withdrawal with flooding.

All the above comments apply as well when a gas other than air is used in the bin. The critical property is the viscosity of the gas. The permeability tests run by Jenike & Johanson are usually done with air at room temperature. When the gas or the temperature is different, the coefficient of permeability needs to be modified, as discussed below.

Section V - Air permeability test results

Values of air permeability are expressed as a function of the bulk density of the solid. These values are used in the calculation of critical flow rates, given in Section IV, and in the design of air permeation systems. Permeability is also used for purge vessel or dryer design and when fluidization is recommended.

The equation given in this section and the test method are both based on the assumption of laminar flow of gas. This assumption is generally valid for all powders and for most materials which have a significant portion of particles less than 20 mesh in size.

The permeability factor K has dimensions of velocity and is inversely proportional to the viscosity of the gas. The results can be adjusted to elevated temperatures and to other gases by multiplying the constant K_0 by the ratio of the viscosity of air at room temperature to that of the gas at the temperature in question.

Section VI - Chutes

A chute, unlike a hopper, does not operate full of material. As an example, a transfer chute between two conveyors encloses and directs the stream of material, but discharges the material before any level accumulates.

The chute design concepts given below apply only to a fast (i.e., accelerated) flow mode in which material flows in contact with the chute bottom and side walls without contact with the top surface. A good rule of thumb is that a chute should be sized such that it is no more than one-third full in cross section over the entire chute length. If the chute fills with enough material, it may have to be considered a hopper. This case would require a proper hopper design to ensure reliable flow.

In order to maintain material flow in a chute, its inside surface walls must be steep enough and have sufficiently low friction to allow the material to flow along them. This is dictated by the friction between the chute surface and the bulk material. This friction is dependent upon the roughness of the surface and the impact pressure caused by the material hitting it.

The chute angle test measures the critical chute angles required for cleanoff as a function of impact pressure for the limiting case where the material adheres to the surface. These angles are used to determine the minimum chute angle required at an impact point to overcome adhesion and ensure flow.

The test consists of loading a sample of the bulk solid on a representative coupon of the chute surface with a range of loads to represent different impact pressures. After each load is applied for a few seconds, the load is removed and the coupon is inclined about a distant pivot point. The angle at which the bulk solid slides is plotted as a function of impact pressure. Results are given in Section VI of the test report.

The impact pressure, P , may be approximated using the following formula:

$$P = \text{impact pressure} = \frac{\rho V_1^2 \sin^2 \theta}{g} \quad (9)$$

where:

- ρ = bulk density (pcf)
- V_1 = velocity before impact (for the case of a simple freefall, $V_1^2 = 2gh$), (ft/s)
- θ = angle of impact between incoming stream and chute surface (degrees)
- g = acceleration due to gravity (32.2 ft/s²)

A factor of 5° to 10° should be added to the highest measured value given to ensure cleanoff.

Other design considerations include: controlling the particle stream, minimizing (de)accelerations of particles, minimizing wear and power requirements on downstream conveyors, minimizing abrasive wear of the chute itself, controlling dust, minimizing attrition. For additional information on many of these considerations, see Jenike & Johanson's paper #145, "Design Principles for Chutes to Handle Bulk Solids."

GLOSSARY OF TERMS AND SYMBOLS

Arching	- a no-flow condition in which material forms a stable arch (dome, bridge) across the bin
Bin	- container for bulk solids with one or more outlets for withdrawal, either by gravity alone or by flow-promoting devices which assist gravity
Bunker	- same as bin, often used in reference to storing coal
Chute	- means of collecting material which, unlike a hopper, does not operate full
Cylinder	- vertical part of a bin
Discharger	- device used to enhance material flow from a bin but which is not capable of controlling the rate of withdrawal
Effective Head	- convenient way to express consolidating pressure by dividing it by bulk density; see eqs. (1) and (2)
Elevator	- same as bin, often used in reference to storing grains
Expanded flow	- flow pattern that is a combination of mass flow and funnel flow
Feeder	- device for controlling the rate of withdrawal of bulk solid from a bin
Flow channel	- space in a bin through which a bulk solid is actually flowing during withdrawal
Flooding, flushing	- condition where an aerated bulk solid behaves like a fluid and flows uncontrollably through an outlet or feeder
Funnel flow	- flow pattern in which solid flows in a channel formed within stagnant material
Hopper	- converging part of a bin
Mass flow	- flow pattern in which all solid in a bin is in motion whenever any of it is withdrawn
Piping	- same as ratholing
P-FACTOR	- the ratio of the applied solids compacting pressure to the solids pressure during steady gravity flow; see eqs. (3) to (6)
Ratholing	- a no-flow condition in which material forms a stable vertical hole within the bin
Silo	- same as bin

A	- area of impact of falling stream of solids, area over which external load is applied, or area of outlet, ft ²
a	- acceleration along a chute surface, ft/sec ² ; see eq. (11)
a _z , a _y	- vertical and horizontal accelerations, respectively, ft/sec ²
B	- span across a bin at any elevation of the bin, ft.
BC	- minimum diameter of a circular outlet in a mass flow bin, ft.
BF	- minimum width of a rectangular outlet in a funnel flow bin, ft.
BP	- minimum width of an oval outlet in a mass flow bin, ft.
D	- diameter of cylindrical portion of a bin, ft.
DF	- critical ratholing (piping) dimension, ft.
EH	- effective consolidating head, ft.
F	- force from an external load on material, lb.
f _c	- unconfined compressive strength of a solid, psf
g	- gravitational constant = 32.2 ft/sec ²
H	- height of cylinder, ft.
h	- height of fall of material, ft.
k	- ratio of horizontal to vertical pressure
K	- permeability, ft/sec.
K ₀	- permeability constant, ft/sec.
L	- length of hopper outlet, ft.
m	- parameter equal to 0 for rectangular outlet and equal to 1 for circular or square outlet
p	- liquid or gas pressure, psf
Q	- maximum discharge rate of a coarse solid, lb/sec.
R	- hydraulic radius, ft.
S	- shearing force applied to a shear cell, lb.; distance along chute surface, ft.
V	- normal force applied to a shear cell, lb.

V_1	- velocity of stream of particles just before impact on a chute surface, ft/sec.
W	- width of rectangular bin cylinder, ft.
w	- weight flow rate into the bin, lb/sec.
y	- horizontal coordinate, ft.
z	- vertical coordinate, ft.
\square GAMMA	- bulk density, pcf
\square DELTA	- effective angle of internal friction of a solid during flow, degrees
\square	- impact angle on chute surface, degrees
\square_c , THETA-C	- maximum recommended angle (from vertical) of conical hoppers and end walls of transition hoppers for mass flow, degrees
\square_p , THETA-P	- maximum recommended angle (from vertical) of side walls of transition or wedge-shaped hoppers for mass flow, degrees
μ , MU	- $\tan(\text{PHI-PRIME})$
\square , SIGMA	- normal stress applied to a shear cell, psf
\square_1 , SIGMA1	- major consolidating pressure, psf
\square TAU	- shearing stress applied to a shear cell, psf
\square , PHI-PRIME	- kinematic angle of friction between a solid and a wall, degrees
\square , PHI	- angle of internal friction of a solid in incipient flow, degrees

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- 237. Lone Star Case History
- 238. Glass Quality Improved with Reduced Segregation
- 274. Paper Mill Tackles Material Flow Problem at Hot Lime Bin

Segregation and Blending

- 107. Understanding and Eliminating Particle Segregation Problems
- 139. In-Bin Blending Improves Process Control
- 161. Tumble Blending with Mass Flow Containers Improves Productivity and Quality
- 166. Blending and Segregation (capabilities available from Jenike & Johanson)
- 178. How to Mix Dry Bulk Solids and Maintain Blend Integrity
- 207. Analyzing and Overcoming Industrial Blending and Segregation Problems
- 230. Bench-Scale Segregation Tests as a Predictor of Blend Sampling Error

Inserts

- 30. The Use of Flow-Corrective Inserts in Bins
- 88a. Controlling Flow Patterns in Bins by Use of an Insert
- 119. Versatile BINSERT® System Solves Wide Range of Flow Problems

Bin Loads

- 157. Load Development and Structural Considerations in Silo Design
- 260. Silo Failures: Case Histories and Lessons Learned

Pneumatic Conveying

- 109. Interfacing Storage Bins with Pneumatic Conveying Systems
- 115. Pneumatic Conveying: Principles of Operation
- 174. Characterization of Dilute Gas-Solids Flows Using the Rescaled Range Analysis
- 180. Pneumatic Conveying Services
- 226. Troubleshooting Pneumatic Conveying Problems
- 246. Propel Your Pneumatic Conveying System to Higher Efficiency

Purge and Conditioning Vessels

- 165. Mass Flow Purge and Conditioning Vessels
- 184. Uniform Conditioning of Bulk Solids in Processing Vessels
- 212. Gravity Flow Processing Vessels
- 215. Uniform Purging of Resins in Contact Bed Purge Vessels

Stockpile Design

- 185. Tunnel Reclaim from Ore Stockpiles
- 187. Design of Stockpiles in Mining Operations

Papeles en Español

- 194. Diseño de Stockpiles en Operaciones Mineras
- 203. Velocidad Minima de Transporte en Sistemas de Transporte Neumático en Fase Diluida
- 255. Propiedades de Fluidez de Los Materiales Solidos A Granel
- 256. Almacenamiento y Flujo de Materiales Solidos a Granel
- 257. Diseño y Operacion de Stockpiles en Operaciones Mineras

Miscellaneous

- 89. Measuring and Use of Wear Properties for Predicting Life of Bulk Materials Handling Equipment
- 105. Ultrahigh Molecular Weight Polyethylene Abrasion Resistant Liners Facilitate Solids Flow in Hoppers
- 163. Identifying and Controlling Silo Vibration Mechanisms: Part I and Part II
- 164. Survey of Industrial Plants Handling Bulk Solids

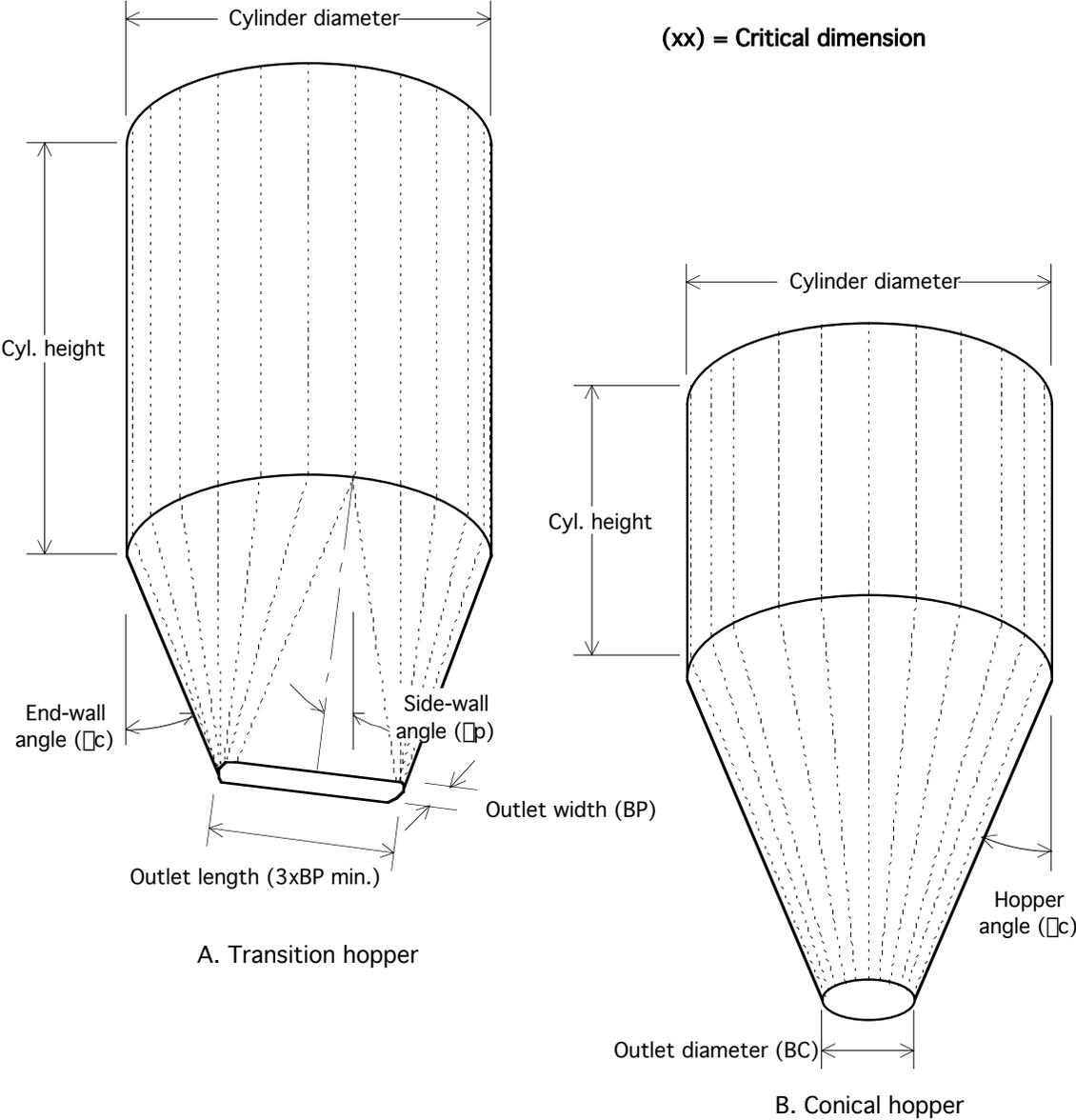


Figure A1
Examples of Mass Flow Bins

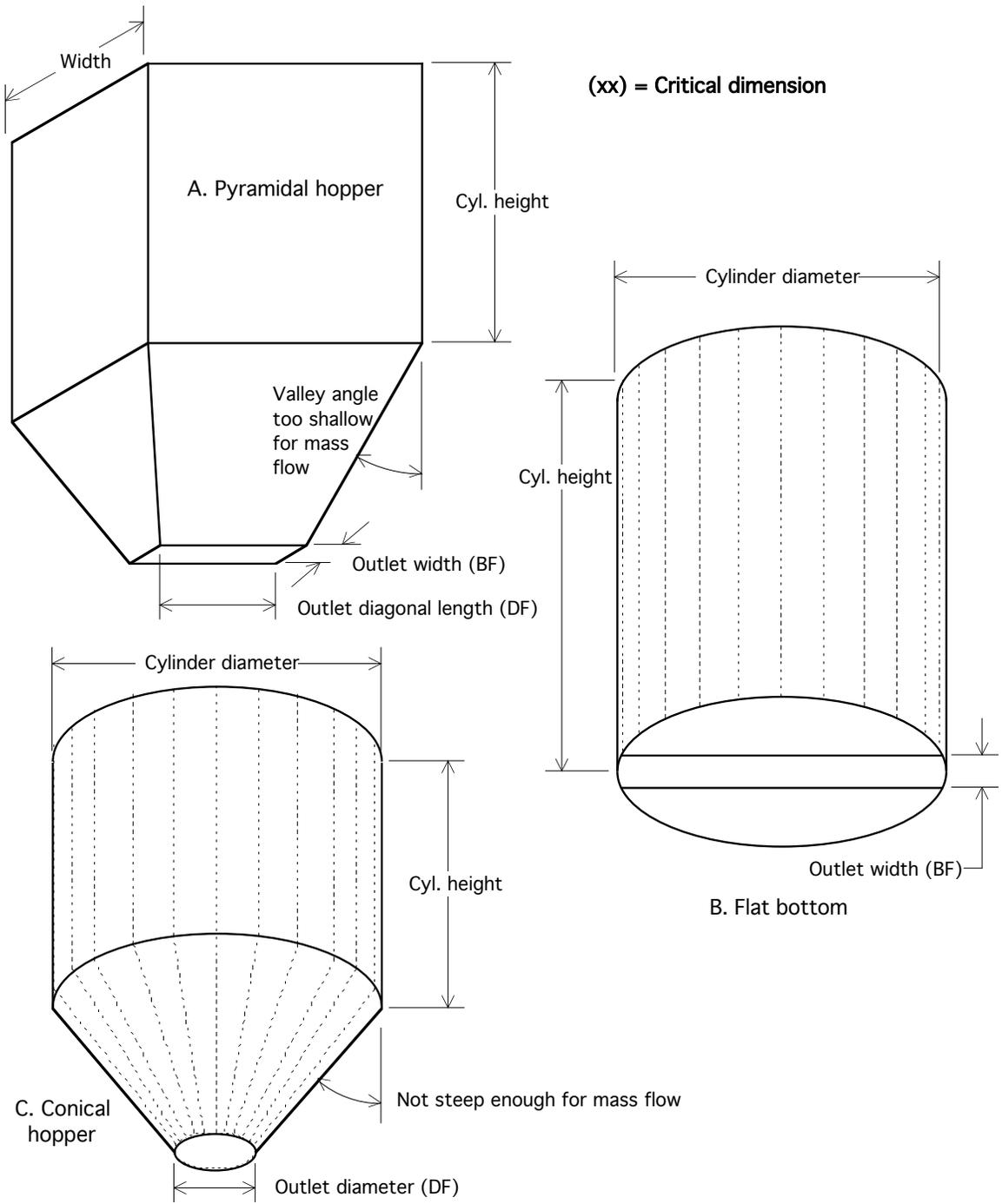


Figure A2
Examples of Funnel Flow Bins

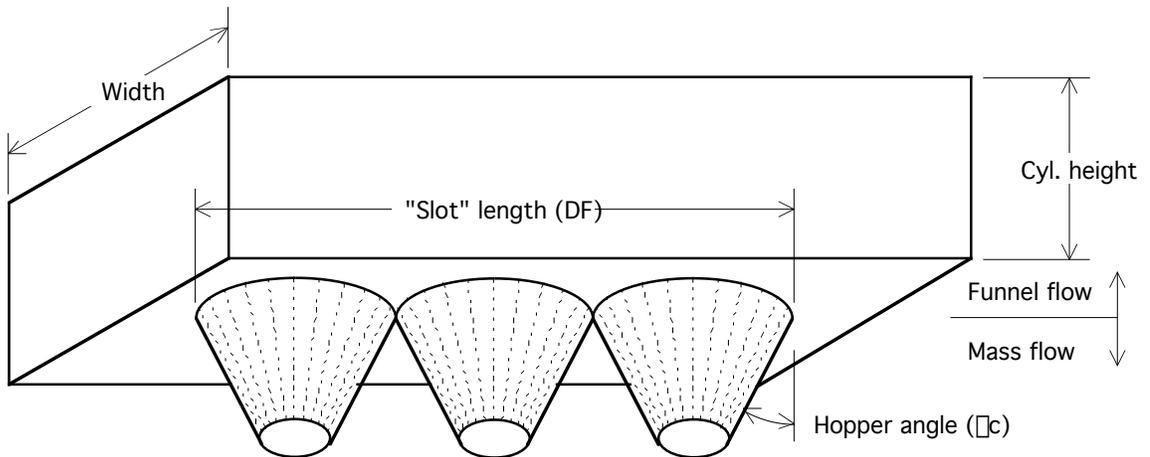
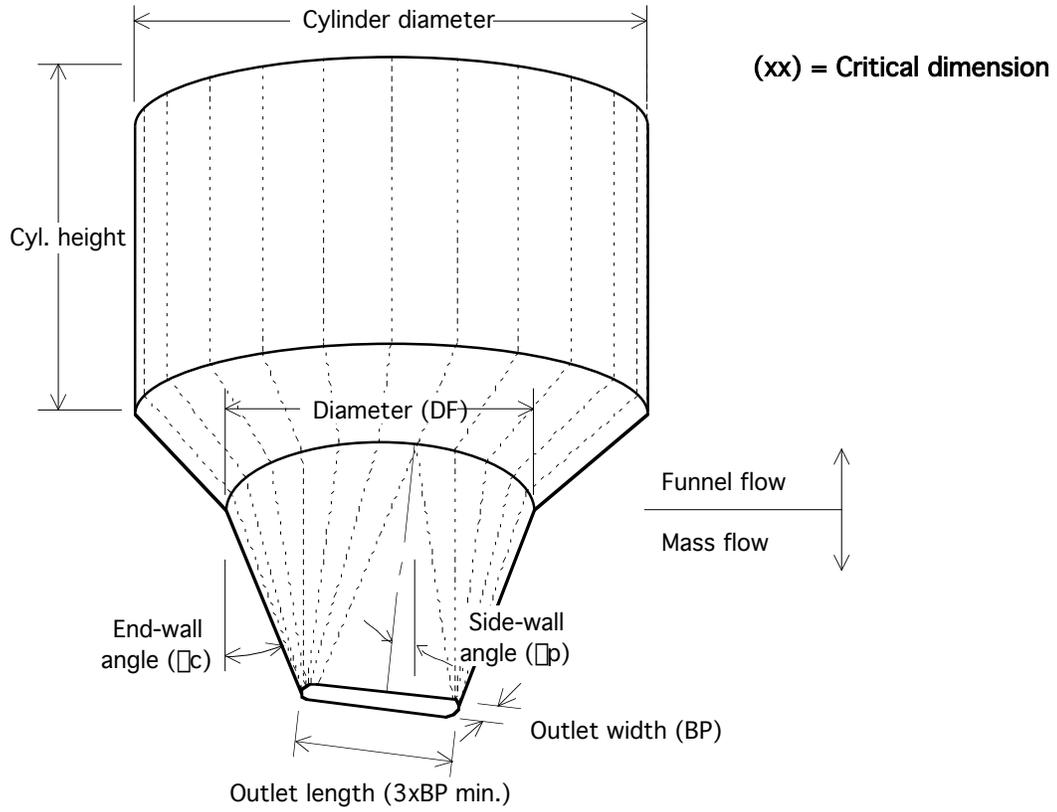


Figure A3
Examples of Expanded Flow Bins