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Evaluation of Laboratory Tire Tread and Sidewall Strength (Plunger Energy) Test Methods

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16. Abstract

Under the TREAD Act, NHTSA was assigned the task of revising and updating the Federal Motor Vehicle Safety Standards (FMVSS) for tires. This effort included research to support a possible update or replacement of the tire strength test contained in the FMVSS Nos. 109 and 119. The tire strength test was designed in the 1960s to evaluate the strength of the reinforcing materials in bias-ply tires and their resistance to road hazards. In this test, a steel plunger is forced perpendicular to the tread of a mounted and inflated tire until the tire ruptures (with the resulting air loss), or the plunger is stopped by reaching the rim. The plunger penetration distance and the force test points are then used to calculate an average breaking energy that must exceed the required "minimum breaking energy." For modern radial tires, which have flexible sidewalls and high-strength steel belt packages, the vast majority of plunger strength tests "bottom-out" on the rim before rupturing the tire.

One part of the research consisted of testing passenger and light truck tires to the strength test in FMVSS No. 109 or 119 at standard or low inflation pressures in order to evaluate instances of plunger bottom-out. All 12 tires tested to the standard FMVSS Strength Test conditions reached the required minimum breaking energy before either bottoming-out (67%), or rupturing (33%). Of eight additional tires tested at low pressure, the two lowest-aspect-ratio tires did not reach the required minimum breaking energy level before bottoming-out. Additional testing was conducted with the ASTM F414-06 standard, which allows for repeats of the FMVSS Strength Test at increasing increments of inflation pressure in order to generate more force per unit of penetration (i.e., more rapid accumulation of energy to avoid bottom-out). The six tires tested to ASTM F414-06 also reached the FMVSS minimum breaking energy before either bottoming-out (66.6%), or rupturing (16.6%). Four of those six tires transitioned from bottoming-out to rupturing when increasingly higher inflation pressures were used. Two of three additional tires tested at low starting pressures also transitioned from bottoming-out to rupturing when increasingly higher inflation pressures were used. One tire that had exceeded the FMVSS minimum breaking energy requirements at 30 psi test pressure, ruptured below the FMVSS requirement at 38 psi, indicating that extrapolations of energy levels at lower pressures may not always be predictive of a test at a higher pressure.

Six passenger tire models were also tested using an experimental sidewall bruise/strength test and generated statistically different levels of bruise width, penetration, and rupture force between 1-, 2-, and 3-ply sidewall tires.

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Executive Summary

Under the Transportation Recall Enhancement, Accountability and Documentation (TREAD) Act, the National Highway Traffic Safety Administration (NHTSA) was assigned the task of revising and updating the Federal Motor Vehicle Safety Standards (FMVSS) for tires. This effort included research to support a possible update or replacement of the current tire strength (also referred to as "plunger energy") test in FMVSS Nos. 109 and 119. The FMVSS Tire Strength Test was designed in the 1960s to evaluate the strength of the reinforcing materials in bias-ply tires and their resistance to road hazards. The test consists of forcing a 19-mm (¾-inch) diameter cylindrical steel plunger with a hemispherical end perpendicularly into to the centermost tread rib of a mounted and inflated tire at the rate of 50-mm (2inches) per minute. This is repeated at five equally spaced points around the circumference of the tire. To pass the test, the average energy of the test points must exceed the appropriate "minimum breaking energy" specified for that tire.

FMVSS No. 109 was introduced in 1967 and primarily regulated passenger car tires. FMVSS No. 119 was introduced in 1974 and regulated tires for vehicles other than passenger cars. Since then, there has been a steady introduction of larger tire rim codes and smaller aspect ratios. During that same time period, the tire industry almost totally converted passenger and light truck tire technology from bias and bias-belted designs to radial designs. In the 2002 Notice of Proposed Rulemaking (NPRM) for FMVSS No. 139, NHTSA stated concerns that radial tires possess flexible sidewalls that easily absorb deflections, and high-strength belt packages that far exceed the strength requirements of the original bias-tire strength test. As a result, plunger strength tests will often bottom-out on the rim rather than break the reinforcing materials in a radial tire. This issue is said to be even more prevalent in low-aspect-ratio (low-profile) tires, which have less available section height for the plunger to travel, generating the required minimum breaking energy (this energy is a product of both plunger force and travel). In light of these issues, the 2002 NPRM for the FMVSS No. 139 proposed replacing the current strength test for passenger tires in the FMVSS No. 109 with a test modeled after the SAE J1981 Road Hazard Impact Test. However, the agency's laboratory evaluations of the SAE J1981 test using the wedge-shaped striker head resulted in rim damage rather than air loss or damage to the tire. Consequently, the agency deferred action on the proposal to revise the existing tire strength test in the two standards to allow for additional research, which is the subject matter of this report. In the additional research, the agency tested 18 models of passenger and light truck tires to the plunger strength test procedures in FMVSS No. 109, FMVSS No. 119, or ASTM F414-06 at standard and/or low inflation pressures. A total of 36 tests were conducted on 13 passenger and 5 light truck (load ranges D and E) tire models using 178 individual plunger applications to the tread or sidewall.

One goal of the research was to determine what percentage of tires tested to the applicable FMVSS No. 109 or No. 119 experience plunger bottom-out without reaching the minimum specified breaking energy. Twelve tire models of passenger or light truck tires were tested to the regular FMVSS test conditions. All the tires reached the FMVSS minimum breaking energy level before bottoming or rupturing. Of these 12 tires, 8 (67%) bottomed-out without rupture, and 4 (33%) ruptured. Since all tires tested to the standard FMVSS tests passed before bottoming-out, the researchers did not study use of a deeper well rim (as is done in the FMVSS

No. 109 Laboratory Test Procedure) or use of a higher inflation pressure (as is done in ASTM F414-06) to pass the test.

To gain an understanding of how test pressures affected plunger energy, and to evaluate instances of bottom-out prior to reaching the minimum breaking energy level, a subset of testing was performed using starting test pressures lower than specified in the FMVSS test procedure. Four passenger and four light truck tires were tested to FMVSS No. 109 or No. 119 at reduced starting pressures. Six of the tires reached the minimum breaking energy level before bottom-out or rupture. However, the two lowest aspect ratio (35 series) passenger tires of different models did not reach the required energy level before bottom-out occurred. All four light truck tires ruptured before bottoming-out, while none of the four passenger tires ruptured. These results were useful in examining the effects of inflation pressure on plunger force and travel, and they highlight the difference that the additional section height of the light truck tires provided when compared to the low-aspect-ratio (low section height) passenger tires.

The FMVSS No. 109 specifies tire test pressures of 75 percent to 87 percent of the maximum sidewall pressure listed on the tire sidewall. This research investigated means of modifying the FMVSS Strength Test to avoid plunger bottom-out and the need to remount on deeper well rims (which may not always be available) when minimum energy levels are not achieved. NHTSA evaluated nine passenger car tires with the ASTM F414-00 (later approved as ASTM F414-06), which allows for repeats of a tread plunger strength test at increasing increments of inflation pressure to generate more force per unit of penetration (i.e., more rapid accumulation of energy to avoid bottom-out). The six passenger tires tested to ASTM F414-06 also reached the FMVSS minimum breaking energy level before either bottoming-out (66.6%), or rupture (16.6%). One tire ruptured at standard pressure, four tires required the pressure to be increased for additional plunger applications to achieve rupture, and one tire continued to bottom-out at pressure increases up to the maximum pressure listed on the tire sidewall. The results consistently indicated that increasing the test inflation pressure of the tire generates more force on the tread per unit travel. Thus, the use of higher inflation pressures significantly enhances the likelihood of reaching minimum breaking energy or “breaking” (rupturing) a radial tire before bottoming-out on the rim.

Tests on three passenger tires were also conducted with ASTM F414-06 using a lower-than-specified pressure at the start of testing. Again, increasing the test inflation pressure resulted in two of three tires transitioning from bottoming-out on the rim to rupturing. However, one tire that had exceeded the FMVSS minimum breaking energy requirements at increased 30- and 34-psi test pressures, ruptured at an energy below the FMVSS requirement at 38 psi. This indicates that extrapolations of energy levels at lower pressures may not always be predictive of a test at a higher pressure.

The final goal of the agency research was to evaluate tire sidewall strength/bruise resistance. A sidewall test was proposed that used existing FMVSS tread strength test fixtures in an attempt to duplicate the sidewall bulges or broken cords seen in tires damaged during service. This method was used on five passenger and two light truck tires to examine the concept. The sidewall strength results show a difference between tire sidewall constructions. These results suggested plunger penetration and breaking force were significantly influenced by the number of plies in the tire sidewall.

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1.0 INTRODUCTION

Under the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000, the National Highway Traffic Safety Administration (NHTSA) was assigned the task of revising and updating the Federal Motor Vehicle Safety Standards (FMVSS) for tires. Part of this effort included research to support a possible update or replacement of the current tire strength (also referred to as "plunger energy") test in the Code of Federal Regulations Title 49, Parts 571.109 (FMVSS No. 109)[1] and No. 571.119 (FMVSS No. 109).[2] The equipment and procedures in the tire strength test in the FMVSS No. 109, which was issued in 1967, were adopted from the 1965 version of SAE J918 - *"Passenger Car Tire Performance Requirements and Test Procedures"* The test was designed in the 1960s to evaluate the strength of the reinforcing materials in bias-ply tires and their resistance to road hazards.

The tire strength test in FMVSS Nos. 109 and 119 consists of forcing a 19-mm (¾-inch) diameter cylindrical steel plunger with a hemispherical end perpendicularly into to the centermost tread rib of a mounted and inflated tire at the rate of 50-mm (2-inches) per minute. This is repeated at five equally spaced points around the circumference of the tire[3]. Per the Federal standards, the force and penetration (travel) of each plunger application is recorded. If the tire fails to break before the plunger is stopped by reaching the rim (plunger "bottom-out"), the force and penetration is recorded as the rim is reached. The test points are then used to calculate an average breaking energy $W = [(FxP)/2]$, where W = Energy, inch-pounds; F = Force, pounds; and P = Penetration, inches. To pass, the average energy must exceed the appropriate "minimum breaking energy" specified for that tire.

FMVSS No. 109 was introduced in 1967 and primarily regulates passenger car tires. FMVSS No. 119 was introduced in 1974 and regulates tires other than for passenger cars. Since that time, there has been a steady introduction of larger tire rim codes and lower-aspect ratios. From 1949 to 1970, the majority of passenger tires had aspect ratios of 90 to 80-series on 10 to 15-inch diameter wheels.[4] The bias and bias-belted tire of the 1970s included 78 to 50 series tires in 13, 14, and 15 rim codes. More recently, the Tire Business publication has tracked the growth of tire aspect ratios[5] and rim sizes[6] recognized by the Tire and Rim Association since 1985. In 1985, there were five aspect ratios: 80, 75, 70, 60, 50; and five rim codes of 12 to 16. By 2009, there were 12 aspect ratios, ranging from 80 to 25 and 13 rim codes of 12 to 24. Since then, replacement tire and wheel packages have become available in aspect ratios as small as 20 series[7] and rim codes up to 32.[8] An almost total conversion of passenger and light truck tire technology from bias and bias-belted designs to radial designs also occurred in this timeframe.[9]

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[1] CFR 49 Part 571.109 Standard No. 109; New pneumatic tires. E-CFR www.gpoaccess.gov/cfr/index.html
[2] CFR 49 Part 571.119 Standard No. 119; New pneumatic tires for vehicles other than passenger cars. E-CFR. www.gpoaccess.gov/cfr/index.html
[3] FMVSS No. 119 specifies testing to be completed three times around the tire for tires of rim code 12 or less.
[4] The TireRack Web site has a tire size conversion chart that contains equivalent sizes from 1949 onward. www.tirerack.com/tires/tiretech/45_conversionchart.html
[5] Tire Business, February 2010, chart "Growth in tire aspect ratios," source the Tire and Rim Association.
[6] Tire Business, February 2010, chart "Growth in auto rim diameters," source the Tire and Rim Association.
[7] E.g. Kuhmo Exasta SPT KU31 375/20R21 103Y, 220/AA/A tires.
[8] E.g. Asanti AF401 or Lexani LT-703 32-inch wheels with 335/30R32 116V Yokohama Parada tires.
[9] Radial tires were 99 percent of passenger tire shipments in 2005 (Modern Tire Dealer 2006, 51).

In regard to the applicability of the bias-tire strength test to modern radial tires, the March 5, 2002 Notice of Proposed Rulemaking (NPRM) for FMVSS No. 139[10] stated:

> "The FMVSS NO. 109 plunger energy or strength test was designed to evaluate the strength of the reinforcing materials in bias-ply tires, typically rayon, nylon or polyester, and it continues to serve a purpose for these tires. However, a radial tire is not susceptible to the kind of failure for which this test was designed to prevent. The flexible sidewalls of radial tires easily absorb the shock of road irregularities.
>
> Because of the belt package, radial tires far exceed the strength requirements of the test and many times the plunger bottoms-out on the rim instead of breaking the reinforcing materials in the radial tire. During the years 1996 through 1998 RMA members reported conducting nearly 19,000 plunger energy (strength) tests on radial tires. There were no[11] reported failures."

Similar issues with the tire strength test were also summarized in the 2006 book, *The Pneumatic Tire* (Gent & Walter):

> "Generally, radial passenger car tires contain a minimum of three plies in the tread region (two belt plies and at least one radial body ply) and rarely fail to achieve the minimum value of plunger energy necessary to meet the test requirements. This test is especially moot for steel belted tires featuring nylon cap or overlay plies added to the belt region to achieve high speed ratings. Also, very low-aspect-ratio tires tend to limit plunger travel which can cause the tire tread region to come in contact with the rim (i.e., "bottom-out") before the requisite level of calculated energy is achieved unless plunger force is allowed to build up against the rigid surface of the rim without further plunger travel."

As indicated in *The Pneumatic Tire*, the minimum breaking energy requirement is both a product of the force and penetration travel of the plunger, combined with the fact that low-aspect-ratio (low-profile) radial tires have much less available travel in which to build energy. For tests where the plunger bottoms-out, the standards specify that the force and penetration are to be recorded at the point *"as the rim is reached,"* or "*just before the plunger is stopped by the rim."*[12] While the regulatory text does not state how to proceed if a plunger application bottoms-out prior to reaching the minimum specified energy, the Laboratory Test Procedure for FMVSS No. 109[13] states: *"If any plunger application contacts the test rim before the minimum specified breaking energy is reached, the tire shall be put on a different rim that has more clearance in the*

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[10] Standard No. 139; New pneumatic radial tires for light vehicles. E-CFR www.gpoaccess.gov/cfr/index.html

[11] Despite the numbers reported in this text, it's important to note that modern radial tires have failed the FMVSS Tire Strength test requirements and were subsequently recalled: E.g. NHTSA Recall Campaign ID Numbers: 08T020000 [Year 2008; 5,300 tires], 04T022000 [Year 2004; 700 tires], 04T012000 [Year 2004; 558 tires], 04T002000 [Year 2004; 221 tires], 01T007000 [Year 2001; 15,425 tires], 97T004000 [Year 1997; 5,070 tires].

[12] FMVSS No. 571.109: *"S5.3.2.2 Record the force and penetration at five test points equally spaced around the circumference of the tire. If the tire fails to break before the plunger is stopped by reaching the rim, record the force and penetration as the rim is reached and use these values in S5.3.2.3."* FMVSS No. 571.119: *"S7.3 Strength. (d) Record the force and the distance of penetration just before the tire breaks, or if it fails to break, just before the plunger is stopped by the rim."*

[13] June 1, 2005. TP-109-09, Laboratory Test Procedure for FMVSS No. 109.

test area, and the test repeated."[14] However, with increasingly lower-aspect-ratio tires coming to market, there may be a limit to the rim well depths available to accommodate the additional plunger travel. Therefore, test labs have reported that it is often necessary to allow the plunger to continue compress the tread against the rim (i.e., the plunger has not yet *reached the rim* or been *stopped by the rim*) until the minimum passing energy is achieved. Employing this tread compression practice on certain rim profiles can yield the unwanted result of bending the plunger.

In light of these issues, the March 5, 2002, NPRM for the upgrade of the tire safety standards in the new FMVSS No. 139 proposed replacing the current tire strength test with a test modeled after the SAE J1981 Road Hazard Impact test(CFR 49 Part 571). However, the agency's laboratory evaluations of the SAE J1981 test using the wedge-shaped striker head resulted in rim damage rather than air loss or damage to the tire. The June 26, 2003, FMVSS No. 139 final rule stated: *"…the agency concludes that the SAE road hazard impact test is not suitable to evaluate the capability of a tire to resist damage from impacts with road hazards."*(Gent & Walter)Consequently, the agency deferred action on the proposal to revise the existing FMVSS Strength test in the two standards to allow for additional research in this area, which is the subject matter of this report.

In this additional research, the agency tested 18 models of passenger and light truck tires to FMVSS Nos. 109 or 119 limits, at standard or low inflation pressure, to evaluate instances of plunger bottom-out and pressure effects. Testing was conducted on 13 passenger and 5 light truck (load ranges D and E) tire models selected to give the widest possible range of design parameters. The test tires had widths from 155 to 345 millimeters, aspect ratios from 80 to 30, rim codes from 12 to 28, and 1 to 3 radial body plies. One goal of the research was to determine what percentage of tires tested to the Federal or ASTM standards experience plunger bottom-out without reaching the minimum specified breaking energy.

The research also sought to evaluate means of modifying the FMVSS Strength test to avoid plunger bottom-out. The agency evaluated nine passenger car tires with the then-draft version of the ASTM F414-06 *Standard Test Method for Energy Absorbed by a Tire When Deformed by Slow-Moving Plunger*.[15] The F414 test standard was under review in ASTM F09.30 task group at the time, and was later approved in 2006 as the F414-06. Since then it has been replaced by a 2009 version, F414-09. The ASTM F414-06 included a clause that if a "bottom-out" occurred, the tire could be considered as passing any standard; or the tire could continue to be retested at incrementally higher inflation pressures until rupture or bottom-out occurred at the maximum allowable pressure. The ASTM definition[16] of bottom-out is somewhat different than the FMVSS in that the end of test is defined by stoppage of the "inside surface" of the tire against the rim rather than the stoppage of the plunger as defined in the FMVSS. The new approach in the F414-06 was to be explored as a means of preventing plunger bottom-out in tires with minimal section height.

[14] The Laboratory Test Procedure for FMVSS No. 119 does not contain this instruction.

[15] The F414 test standard was under review in ASTM F09.30 task group at the time and was finally approved in 2006 as the F414-06. In 2009, it was replaced by an updated F414-09 version.

[16] ASTM F414-06 defines *bottom-out, v*—to deform a tire by radial load on the tread until radial movement of the inside surface is stopped by the rim or other tire inside surface.

The final goal of the agency research was to evaluate tire sidewall bruise resistance/strength, a region prone to separations/bubbles from impacts with potholes, curbs, or other road hazards.[17] Literature states that tires with larger rim diameters and lower-aspect-ratio, an increasing popular trend, are more susceptible to being damaged in the sidewall area due to such impacts. This damage, generally a rubber-to-fabric delamination and/or broken body cords, appears as a bulge (blister) in the sidewall that can appear immediately, or some period of time after the impact has occurred. This bulge can create a weak area in the tire, which poses a possible safety concern because the tire may eventually blowout at the point of separation or broken cords. Therefore, a test was examined that used the existing FMVSS Strength test fixtures in an attempt to evaluate tire sidewall bruise resistance/strength.

[17] E.g. Tire Tech Information/General Tire Information: "Sidewall Separations/Bubbles." www.tirerack.com/tires/tiretech/techpage.jsp?techid=159

2.0 TEST TIRES AND WHEELS

Eighteen tire models were selected for testing to give a wide range of tire sizes, aspect ratios, and rim codes. The test tires had widths from 155 to 345 millimeters, aspect ratios from 30 to 80, and rim codes from 12 to 28. They were selected to evaluate the limits of the test equipment in terms of physical dimensions and possible forces required to rupture the tire. Five models of commercially available light truck (LT) tires were selected to allow evaluation of the testing for FMVSS No. 119 requirements. The tires focused on the extremes of sizes from those used for off-road high flotation, to those designed for ultrahigh performance applications. The 13 models of commercially available passenger tires were selected to allow evaluation of the testing for FMVSS No. 109 requirements. The passenger tire models included very small (155R12) to very large (325/30R28) tires. All tires tested were DOT-approved for street use. While tires from the smaller rim codes were selected from typical all-season designs, most of the available tires in the 18 to 28-rim codes were high performance designs. A complete list of the tires is found in Table 2.1. Figure 2.1 contains a photograph of most, but not all, of the tires tested.

The tires were mounted on wheels with appropriate model rim dimensions. Wheels were standard purchased items from various commercial sources. All were the approved rim width and contour for the tire size as specified by TandRA (Tire and Rim Association) or ETRTO (European Tire and Rim Technical Organization). The tire and wheel assemblies were then conditioned for a minimum of three hours at the specified test pressure. The assembly was then divided into five equally spaced test point locations. The test points are generally pre-labeled at 0 degrees, 72 degrees, 144 degrees, 216 degrees, and 288 degrees to denote the radial distance from the Tire Identification Number (DOT number).

Table 2.1 Test Tires Specifications

Tire Type	Construction	Designation	Tire Brand Name	Tire Model	Tire Size	Test Wheel Size
M7	Light Truck	High Flotation	BFGoodrich	MUD Terrain T/A KM	35x12.50R18LT LRD	18x10J
M5	Light Truck	High Flotation	BFGoodrich	All Terrain T/A KO	37x12.50R20LT LRD	20x10J
T1	Light Truck	LT Metric	Mickey Thompson	Baja Radial MTZ Tire	LT375/50R18 LRE	18x12J
G5	Light Truck	LT Metric	Goodyear	WRANGLER AT/S	LT275/65R20 LRE	20x8J
R1	Light Truck	LT Metric	Pirelli	Scorpion ATR	LT325/45R24 LRE	24x11J
D1	Passenger	Metric	Arizonian [Discount Tire]	Premium Metric	155R12	12x4
C1	Passenger	Metric	General	Ameri G4S	155/80R13	13x4.5J
M2	Passenger	Metric	Michelin	Pilot Sport Cup	345/30R18	18x12J
A1	Passenger	Metric	Avon	Tech ST	275/45R20	20x9J
K1	Passenger	Metric	Kumho	ECSTA STX	305/40R23	23x11J
M8	Passenger	Metric	BFGoodrich	gForce T/A KDW 2	305/35R24	24x11J
Y1	Passenger	Metric	Yokohama	ADVAN ST	305/35R24	24x11J
K2	Passenger	Metric	Kumho	ECSTA STX	325/35R28	28x10.0

Tire Type	Construction	Designation	Tire Brand Name	Tire Model	Tire Size	Test Wheel Size
M9	Passenger	P-Metric	Uniroyal	TigerPaw AWP	P155/80R13	13x4.5B
U1	Passenger	P-Metric	Dunlop	SP Sport 5000	P205/60R15	15x6J
M6	Passenger	P-Metric	BFGoodrich	gForce T/A Drag Radial	P345/30R18	18x12J
Z1	Passenger	P-Metric	Fuzion	ZRi	P275/45R20	20x9J
C6	Passenger	P-Metric	Continental	CrossContact UHP	P305/40R23	23x11J

Figure 2.1 Test Tires

3.0 TIRE PLUNGER STRENGTH TEST EQUIPMENT AND PROCEDURES

All laboratory plunger energy (strength) tests were completed under contract by Akron Rubber Development Labs (ARDL) in Akron, Ohio. The following sections detail the test equipment and various test methods evaluated.

3.1 Tire Strength Test Fixture

The plunger energy fixture was designed to fit into an existing MTS load frame (see Figure 3.1 and Figure 3.2**).** The 19-mm (¾ -inch) diameter cylindrical steel plunger specifed in FMVSS No. 109, SAE J 918 and in ASTM F414-06 was obtained for the testing. The FMVSS Nos. 109 and 119 require this one size for passenger tires and light truck tires through load range H. The load frame was computer controlled and programmed to travel at the required 50.8 mm (2.0 inches) per minute. It was also capable of recording the load and deflection during each attempted penetration. Stopping of the test was determined by the test operator, either when the plunger ruptured the tire or bottom-out occurred. When the plunger pushed the tread of tire until contact with the rim was made, the load increased rapidly but the tire may not have ruptured. Often the rim contour caused the plunger to be deflected off to the side, bending the plunger. Therefore, careful operation of the equipment was necessary as the plunger neared bottom-out.

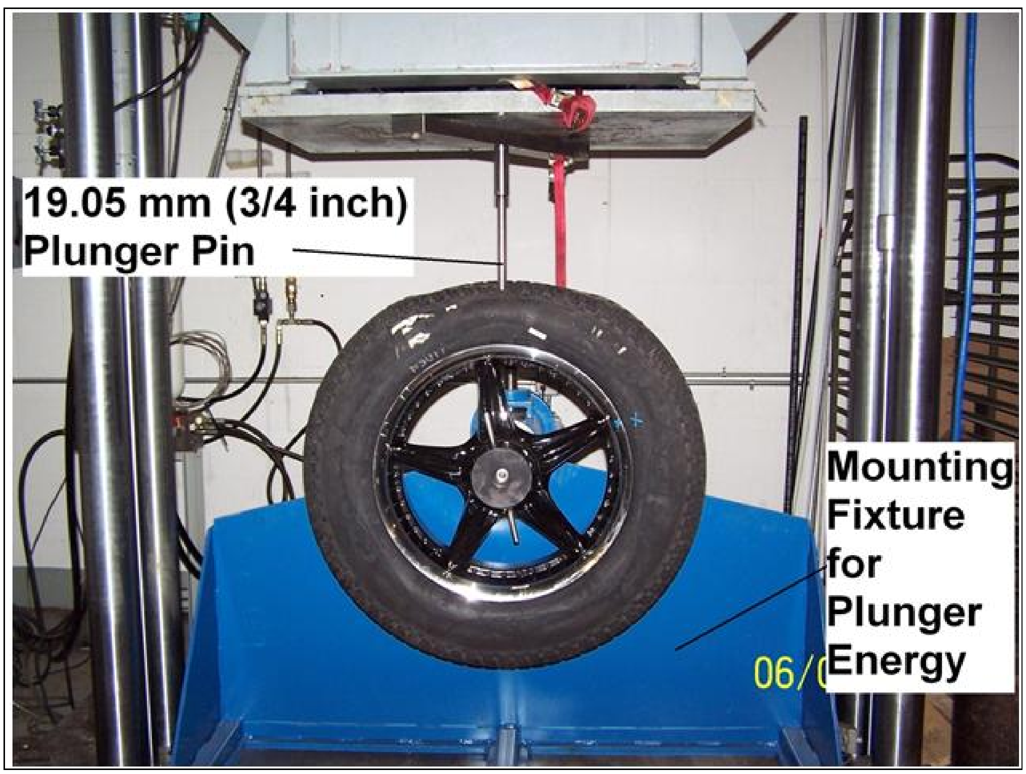

Figure 3.1 Plunger Energy Machine

Figure 3.2 MTS Load Frame and Computer

3.2 FMVSS No. 109 Test Procedure

The FMVSS No. 109 test procedure includes preparation of the tire as previously discussed, including mounting the tire and inflating to pressure specified in Table II of the standard (see Table 3.1).[18] The bold pressures in the table are the maximum inflation pressures found on the tire sidewall. The second and third lines of numbers are the pressures used for the test type described in the first column.

Table 3.1 FMVSS NO. 109 Pressure Table II

Test type	Tires other than CT tires									CT tires			
	psi				kPa					kPa			
	32	**36**	**40**	**60**	**240**	**280**	**300**	**340**	**350**	**290**	**300**	**350**	**390**
Physical dimensions, bead unseating, tire strength, and tire endurance	24	28	32	52	180	220	180	220	180	230	270	230	270
High-speed performance	30	34	38	58	220	260	220	260	220	270	310	270	310

The tire is then conditioned at room temperature (no temperature range is specified) for a minimum of three hours. The pressure is then adjusted to the specified test pressure based on the maximum pressure listed on the sidewall. The test is conducted by installing the tire/wheel assembly in the test machine and forcing a 19-mm (3/4-inch) diameter cylindrical steel plunger

[18] Table II in the FMVSS No. 109 was updated January 17, 2013, www.gpo.gov/fdsys/pkg/FR-2013-01-17/pdf/2013-00938.pdf

with a hemispherical end perpendicularly into the tread rib as near the centerline as possible, avoiding penetration into the tread groove, at a rate of 50-mm per minute. The force and penetration is recorded for the five test points equally spaced around the circumference of the tire. If the tire fails to break before the plunger is stopped by reaching the rim, the force and penetration as the rim is reached is recorded and used to calculate the energy for each test point by means of one of the following formulas:

W = [(FxP)/2000}
Where W = Energy, joules;
F = Force, Newtons;
and P = Penetration, mm; or

W = [(FxP)/2]
Where W = Energy, inch-pounds;
F = Force, pounds; and P = Penetration, inches.

To determine the breaking energy value for the tire, the average of the five values is obtained. Figure 3.3 shows a typical load-deflection graph for one test run with penetration taken to rupture. The shaded area is the minimum required energy calculated at the point the test load-deflection curve reaches the minimum. The maximum energy is calculated at the point the tire ruptures.

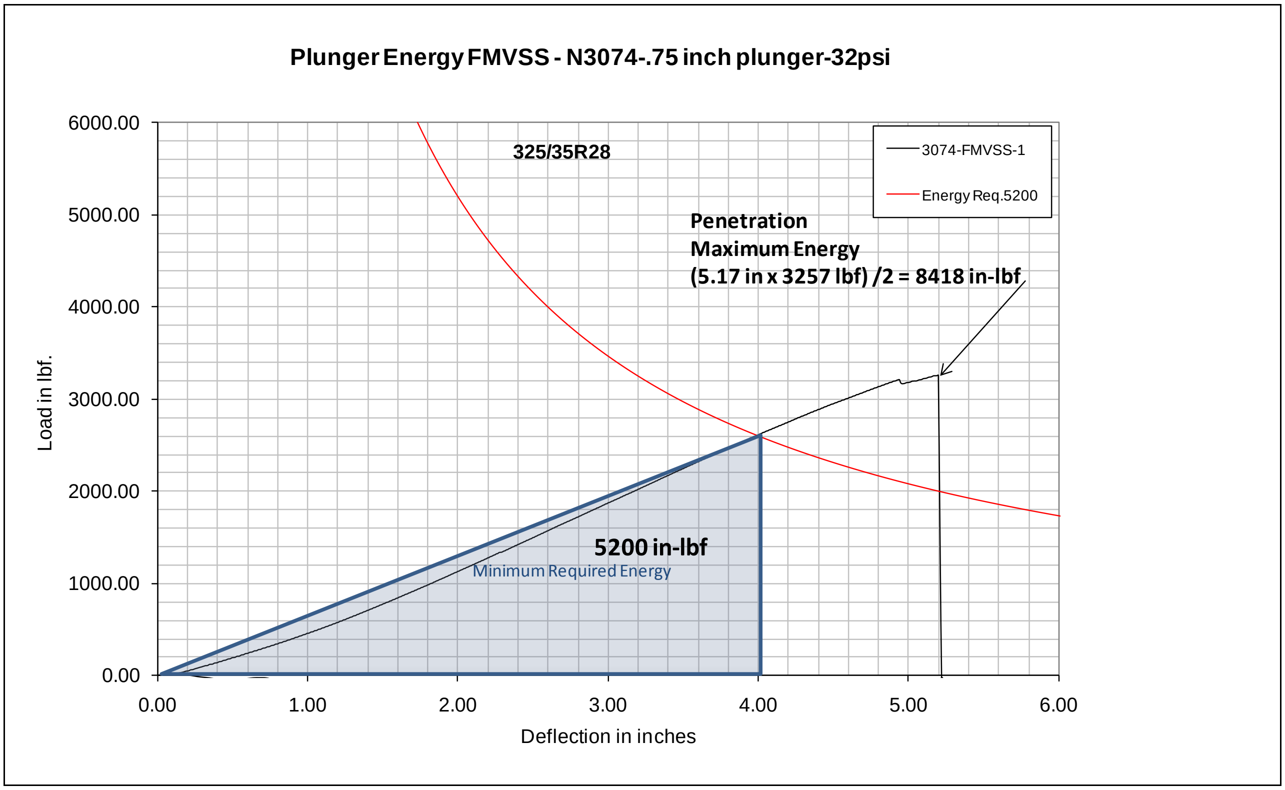

Figure 3.3 Load Deflection Graph

3.3 FMVSS No. 119 Test Procedure

The test method for FMVSS No. 119 is the same as FMVSS No. 109 except that the pressure is based on "the pressure corresponding to the maximum load, or maximum dual load where there is both a single and dual load marked on the tire." Calculation of the result is the same as FMVSS No. 109.

3.4 ASTM F414-06 Test Procedure

ASTM F414-06[19] uses the same basic procedure as FMVSS No. 109 and FMVSS No. 119 (light truck conditions) but is more detailed. Details include machine accuracy, calibration practices, plunger material hardness, and ambient temperature limits 18 to 40°C (65 to 105°F), and test inflation pressure tolerances. F414-06 also includes a provision to increase the pressure by 4-psi increments until the tire is ruptured, or if the tire fails to rupture and continues to bottom-out, until the maximum sidewall pressure is reached. The force and penetration values at rupture or bottom-out are then used to calculate the energy using the same formulas as FMVSS No. 109.

3.5 Sidewall Strength Test

An experimental sidewall strength test using the same basic equipment as the crown (tread) strength tests and Bead unseat fixture was also performed using tires of the same models. While noted here for the purposes of the test plan, complete details on the sidewall plunger test and its results are found in Section 6.0.

[19] ASTM F414-06 Standard Test Method for Energy Absorbed by a Tire When Deformed by Slow-Moving Plunger. ASTM International, West Conshohocken, PA.

4.0 LABORATORY PLUNGER STRENGTH TEST PLAN

This study was designed to provide NHTSA with data on plunger bottom-out during FMVSS Nos. 109 and 119 tests of light truck and passenger tires. The ASTM F414-06 tread plunger strength test was only evaluated on passenger tires. An experimental “sidewall bruise” or sidewall strength test was also evaluated on both light truck and passenger tires.

4.1 Passenger Tire Test Matrix

The 13 models of commercially available passenger tires were selected to allow evaluation of the testing for FMVSS No. 109 requirements. Table 4.1 documents the 28 tests completed on passenger tires. Ten tests were completed using the FVMSS No. 109 at standard test pressure. Four tests were completed using the FVMSS No. 109 at a reduced inflation pressure. Six tests were completed using the ASTM F41-06 test method at standard pressure. Three tests were completed using the ASTM F414-06 test method at a reduced pressure. Five sidewall plunger tests were completed using the FMVSS No. 109 “A” dimension to place the plunger on the sidewall and standard FVMSS No. 109 inflation pressure.

Table 4.1 Passenger Tire Test Matrix

Tire Type	FMVSS No. 109 Plunger	ASTM F414-06 Plunger	Sidewall Plunger (Experimental)*	Test Pressure psi (kPa)	Sidewall Plunger FMVSS NO. 109 "A" Dimension (in)	Graph in Appendix
D1	3035			26 (180)		A1
		3035		26(180)		A3
			3034	26 (180)	9.50	A4
M9	3026			26 (180)		A1
		3026		26 (180)		A3
C1	3050			26 (180)		A1
		3050		26* (180)		A3
			3049	26 (180)	10.00	A4
U1	3014			26 (180)		A1
		3014		26 (180)		A3
Z1	3041			26 (180)		A1
		3041		26 (180)		A3
A1	3002			32 (220)		A1
		3002		32 (220)		A3
M8	3008			26 (180) lp		A2
		3008		26 (180) lp		A2
Y1	3028			26 (180) lp		A2
		3028		26 (180) lp		A2
			3029	32 (220)	15.50	A4
K2	3074			32 (220)		A1
C6	3012*			26 (180)		A1
			3012	26 (180)	15.00	A4
K1	3019*			26 (180) lp		A2
	3020			26 (180) lp		A2
		3020		26 (180) lp		A2
			3019	32 (220)	15.00	A4
M2	3038			26 (180)		A1
M6	3005			26 (180)		A1

lp = low test pressure
*If needed, the tread was plugged from the crown region strength tests and the tire was retested for sidewall strength.

4.2 Light Truck Tire Test Matrix

Five models of commercially available light truck tires were selected to allow evaluation of the testing for FMVSS No. 119 requirements. Table 4.2 documents the eight tests completed on LT tires. Two tread plunger tests were completed using the FVMSS No. 119 specified test pressure. Four tread plunger tests were completed at a reduced inflation pressure. Two sidewall plunger tests were completed, one using the FMVSS No. 109 "A" dimension to place the plunger on the sidewall and low inflation pressure, the other using the 75 percent rule from ASTM 2663-07a[20] bead unseating test for plunger placement and standard inflation pressure.

Table 4.2 Light Truck Tire Test Matrix

Tire Type	FMVSS No. 119 Plunger	ASTM F414-06 Plunger	Sidewall Plunger (Experimental)*	Test Pressure psi (kPa)	Sidewall Plunger FMVSS NO. 109 "A" Dimension (in)	Sidewall Plunger ASTM 2663-07 75% Rule "A" Dimension (in)	Graph found in Appendix
M7	3044			32 (220)*lp			A2
			3044	32 (220) swp		15.38	A4
G5	3016			60 (414)*lp			A2
	3018			60 (414)**lp			A2
R1	3032			65 (448)			A1
T1	3023			50 (345)*lp			A2
			3023	50 (345)*lp swp	12.50		A4
M5	3047			50 (345)			A1

lp = low inflation pressure
swp = sidewall plunger
*If needed, the tread was plugged from the crown region strength tests and the tire was retested for sidewall strength.

[20] *F 2663 – 07a Standard Test Method for Bead Unseating of Tubeless Tires for Motor Vehicles With GVWR of 4,536 kg (10 000 lb) or Less.*

5.0 <u>CROWN (TREAD) PLUNGER STRENGTH TEST</u>

5.1 <u>Plunger Penetration</u>

The testing was conducted at an independent test facility using a computer controlled MTS load frame. The evaluation included measurement of the load and deflection values for each test, with documentation of each rupture or bottom-out. A spreadsheet file was created for each tire and set of test conditions. These spreadsheets allowed comparison of required energy versus load deflection curves to determine if minimum required breaking energy is reached before rupture or bottom-out occurred.

Another area examined by this study was test pressure. To gain an understanding of how test pressures affected plunger energy, and to evaluate instances of bottom-out prior to reaching the minimum breaking energy level, several tires were tested at reduced inflation pressures. Therefore, lower-than-normal test pressures were used in some cases to see if the tires would still meet the FMVSS requirements. The requirements for passenger car from tires are found in FMVSS No. 109 Table 1-C (shown in Table 5.1).

Table 5.1 FMVSS No. 109 Table 1-C, Tire Strength Test Requirements

TABLE 1–C—FOR RADIAL PLY TIRES								
Size designation	Maximum permissible inflation							
	PSI			kPa				
	32	36	40	240	280	300	340	350
Below 160 mm:								
(in-lbs) ...	1950	2925	3900	1950	3900	1950	3900	1950
(joules) ...	220	330	441	220	441	220	441	220
160 mm or above:								
(in-lbs) ...	2600	3900	5200	2600	5200	2600	5200	2600
(joules) ...	294	441	588	294	588	294	588	294

Light truck tire requirements are found in Table II of CFR 49 Part 571.119. The table is shown in abbreviated form for light trucks in Table 5.2:

Table 5.2 FMVSS No. 119 Table II, Minimum Static Breaking Energy

Table II - Minmum Breaking Energy						
Tire Characteristic	motorcycle		All 12 rim diameter code or smaller rim size except		**Light truck** and 17.5 rim diameter code or smaller rim	
Plunger diameter (mm and inches)	7.94 mm	5/16"	19.05 mm	3/4 "	19.05 mm	3/4 "
Breaking Energy	J	In-Lbs	J	In-Lbs	J	In-Lbs
Load Range						
A	16	150	67	600	225	2000
B	33	300	135	1200	293	2600
C	45	400	203	1800	361	3200
D			271	2400	**514**	**4550**
E			338	3000	**576**	**5100**
F			406	3600	644	5700
G					711	6300
H					768	6800
J						
L						
M						
N						

Since the test equipment was calibrated in English units, the breaking energy was calculated using the formula for inch-pounds. The average of the five data points was used when available. (Note: The test lab lacked mounting capability for the larger rim code tires, meaning they could not always plug the tires after rupture, or install an inner tube,[21] and thereby could not continue testing after the first rupture. In these cases, the average energy value may be based on averaging less than five plunger applications.) To allow for comparisons, the data was assembled into Table 5.3, with two rightmost columns indicating the total number of plunger applications per test:

Table 5.3 FMVSS Nos. 109 and 119 Plunger Energy Test Results

Tire Type	Tire Number	Size	Construction	Test Pressure (psi)	Max Load (lbf) **Avg. Max. Load**	FMVSS Minimum Energy (Inch-lbf)	Energy Inch-lbf **AVG Energy**	Pass requirement	Stopped before rupture	Rupture
FMVSS No. 109										
D1	N3035	155R12	1 PE +2 ST	26	1766	1950	4871	Y	1	0
D1	N3035	155R12	1 PE +2 ST	26	1465	1950	3741	Y	1	0
D1	N3035	155R12	1 PE +2 ST	26	1460	1950	3667	Y	1	0
D1	N3035	155R12	1 PE +2 ST	26	1513	1950	4011	Y	1	0
D1	N3035	155R12	1 PE +2 ST	26	1457	1950	3697	Y	1	0
AVG	**N3035**	**155R12**	**1 PE +2 ST**	**26**	**1457**	**1950**	**3667**	**Y**	**5**	**0**
M9	N3026	P155/80R13	2PE + 2 ST	26	1591	1950	4199	Y	1	0
M9	N3026	P155/80R13	2PE + 2 ST	26	1591	1950	4205	Y	1	0
M9	N3026	P155/80R13	2PE + 2 ST	26	1563	1950	4140	Y	1	0
M9	N3026	P155/80R13	2PE + 2 ST	26	1578	1950	4182	Y	1	0
M9	N3026	P155/80R13	2PE + 2 ST	26	1607	1950	4263	Y	1	0
AVG	**N3026**	**P155/80R13**	**2PE + 2 ST**	**26**	**1586**	**1950**	**4198**	**Y**	**5**	**0**
C1	N3050	155/80R13	1 PE +2 ST	26	1875	1950	4947	Y	1	0
C1	N3050	155/80R13	1 PE +2 ST	26	1887	1950	4930	Y	1	0
C1	N3050	155/80R13	1 PE +2 ST	26	1863	1950	4958	Y	1	0
C1	N3050	155/80R13	1 PE +2 ST	26	1873	1950	4909	Y	1	0
C1	N3050	155/80R13	1 PE +2 ST	26	1905	1950	4925	Y	1	0
AVG	**N3050**	**155/80R13**	**1 PE +2 ST**	**26**	**1864**	**1950**	**4947**	**Y**	**5**	**0**
U1	N3014	P205/60R15	1PE + 2ST +1N	26	1771	2600	4209	Y	0	1
U1	N3014	P205/60R15	1PE + 2ST +1N	26	1708	2600	4061	Y	0	1
AVG	**N3014**	**P205/60R15**	**1PE + 2ST +1N**	**26**	**1739**	**2600**	**4130**	**Y**	**0**	**2**
Z1	N3041	275/45R20	2 PE + 2 ST + 2N	26	2540	2600	6313	Y	5	0
Z1	N3041	275/45R20	2 PE + 2 ST + 2N	26	2532	2600	6288	Y	1	0
Z1	N3041	275/45R20	2 PE + 2 ST + 2N	26	2547	2600	6325	Y	1	0
Z1	N3041	275/45R20	2 PE + 2 ST + 2N	26	2544	2600	6326	Y	1	0
Z1	N3041	275/45R20	2 PE + 2 ST + 2N	26	2543	2600	6332	Y	1	0
AVG	**N3041**	**275/45R20**	**2 PE + 2 ST + 2N**	**26**	**2541**	**2600**	**6317**	**Y**	**5**	**0**
A1	N3002	275/45R20	2 PE + 2ST	32	2865	5200	7124	Y	1	0
A1	N3002	275/45R20	2 PE + 2ST	32	2845	5200	7070	Y	1	0

[21] Laboratory Test Procedure for FMVSS No. 109, TP-109-09, p. 35 “When repeated [plunger] penetrations are applied to the tire, an inner tube may be installed or the tire may be repaired.”

Tire Type	Tire Number	Size	Construction	Test Pressure (psi)	Max Load (lbf) **Avg. Max. Load**	FMVSS Minimum Energy (Inch-lbf)	Energy Inch-lbf **AVG Energy**	Pass requirement	Stopped before rupture	Rupture
A1	N3002	275/45R20	2 PE + 2ST	32	2846	5200	7072	Y	1	0
A1	N3002	275/45R20	2 PE + 2ST	32	2883	5200	7169	Y	1	0
A1	N3002	275/45R20	2 PE + 2ST	32	2860	5200	7101	Y	1	0
AVG	**N3002**	**275/45R20**	**2 PE + 2ST**	**32**	**2845**	**5200**	**7107**	**Y**	**5**	**0**
M2	N3038	345/30R18	2N + 2F + 1PY	26	1781	2600	3075	Y	1	0
M2	N3038	345/30R18	2N + 2F + 1PY	26	1775	2600	3065	Y	1	0
M2	N3038	345/30R18	2N + 2F + 1PY	26	1779	2600	3065	Y	1	0
M2	N3038	345/30R18	2N + 2F + 1PY	26	1775	2600	3065	Y	1	0
M2	N3038	345/30R18	2N + 2F + 1PY	26	1754	2600	3031	Y	1	0
AVG	**N3038**	**345/30R18**	**2N + 2F + 1PY**	**26**	**1773**	**2600**	**3060**	**Y**	**5**	**0**
C6	N3012	305/40R23	2 R+2ST+2N	26	2746	2600	6827	Y	1	0
C6	N3012	305/40R23	2 R+2ST+2N	26	2699	2600	6713	Y	1	0
C6	N3012	305/40R23	2 R+2ST+2N	26	2765	2600	7123	Y	1	0
C6	N3012	305/40R23	2 R+2ST+2N	26	2718	2600	6819	Y	1	0
C6	N3012	305/40R23	2 R+2ST+2N	26	2670	2600	6621	Y	1	0
AVG	**N3012**	**305/40R23**	**2 R+2ST+2N**	**26**	**2670**	**2600**	**6871**	**Y**	**5**	**0**
M6	N3005	P345/30R18	2PE +2ST +1N	26	1772	2600	3052	Y	5	0
M6	N3005	P345/30R18	2PE +2ST +1N	26	1772	2600	3056	Y	1	0
M6	N3005	P345/30R18	2PE +2ST +1N	26	1772	2600	3051	Y	1	0
M6	N3005	P345/30R18	2PE +2ST +1N	26	1787	2600	3087	Y	1	0
M6	N3005	P345/30R18	2PE +2ST +1N	26	1772	2600	3064	Y	1	0
AVG	**N3005**	**P345/30R18**	**2PE +2ST +1N**	**26**	**1772**	**2600**	**3062**	**Y**	**5**	**0**
K2	N3074	325/35R28	2PE +2ST +2N	32	3257	5200	8418	Y	0	1*
FMVSS No. 119										
R1	N3032	LT325/45R24	2PE +2ST +2N	65	8965	5100	27786	Y	0	1
R1	N3032	LT325/45R24	2PE +2ST +2N	65	8804	5100	27122	Y	0	1
R1	N3032	LT325/45R24	2PE +2ST +2N	65	8844	5100	27332	Y	0	1
R1	N3032	LT325/45R24	2PE +2ST +2N	65	8855	5100	27323	Y	0	1
R1	N3032	LT325/45R24	2PE +2ST +2N	65	8845	5100	27107	Y	0	1
AVG	**N3032**	**LT325/45R24**	**2PE +2ST +2N**	**65**	**8862**	**5100**	**27334**	**Y**	**0**	**5**
M5	N3047	LT37x12.5R20	3PE +2ST +1N	50	3624	4550	7332	Y	0	1
M5	N3047	LT37x12.5R20	3PE +2ST +1N	50	3520	4550	6956	Y	0	1*
AVG	**N3047**	**LT37x12.5R20**	**3PE +2ST +1N**	**50**	**3572**	**4550**	**7144**	**Y**	**0**	**2**
FMVSS No. 109 at Low Pressure										
M8	N3008	305/35ZR24	2PE +2ST +1P	26	2532	5200	5519	NR	1	0
M8	N3008	305/35ZR24	2PE +2ST +1P	26	2236	5200	4757	NR	1	0
M8	N3008	305/35ZR24	2PE +2ST +1P	26	2256	5200	4803	NR	1	0
M8	N3008	305/35ZR24	2PE +2ST +1P	26	2274	5200	4833	NR	1	0
M8	N3008	305/35ZR24	2PE +2ST +1P	26	2248	5200	4787	NR	1	0
AVG	**N3008**	**305/35ZR24**	**2PE +2ST +1P**	**26**	**2236**	**5200**	**4940**	**NR**	**5**	**0**
Y1	N3028	305/35R24	2PE+2ST+2N	26	2068	5200	3883	NR	5	0
Y1	N3028	305/35R24	2PE+2ST+2N	26	2064	5200	3868	NR	1	0

Tire Type	Tire Number	Size	Construction	Test Pressure (psi)	Max Load (lbf) **Avg. Max. Load**	FMVSS Minimum Energy (Inch-lbf)	Energy Inch-lbf **AVG Energy**	Pass requirement	Stopped before rupture	Rupture
Y1	N3028	305/35R24	2PE+2ST+2N	26	2087	5200	3966	NR	1	0
Y1	N3028	305/35R24	2PE+2ST+2N	26	2080	5200	3916	NR	1	0
Y1	N3028	305/35R24	2PE+2ST+2N	26	2081	5200	3926	NR	1	0
AVG	**N3028**	**305/35R24**	**2PE+2ST+2N**	**26**	**2076**	**5200**	**3912**	**NR**	**1**	**0**
K1	N3019	305/40R23	2PE+2ST+2N	26	2791	5200	6479	Y	1	0
K1	N3019	305/40R23	2PE+2ST+2N	26	2781	5200	6464	Y	1	0
K1	N3019	305/40R23	2PE+2ST+2N	26	2797	5200	6516	Y	1	0
K1	N3019	305/40R23	2PE+2ST+2N	26	2760	5200	6386	Y	1	0
K1	N3019	305/40R23	2PE+2ST+2N	26	2752	5200	6401	Y	1	0
AVG	**N3019**	**305/40R23**	**2PE+2ST+2N**	**26**	**2752**	**5200**	**6449**	**Y**	**5**	**0**
K1	N3020	305/40R23	2PE+2ST+2N	26	2829	5200	6776	Y	1	0
K1	N3020	305/40R23	2PE+2ST+2N	26	2738	5200	6369	Y	1	0
K1	N3020	305/40R23	2PE+2ST+2N	26	2782	5200	6597	Y	1	0
K1	N3020	305/40R23	2PE+2ST+2N	26	2736	5200	6382	Y	1	0
K1	N3020	305/40R23	2PE+2ST+2N	26	2724	5200	6332	Y	1	0
AVG	**N3020**	**305/40R23**	**2PE+2ST+2N**	**26**	**2724**	**5200**	**6491**	**Y**	**5**	**0**
FMVSS No. 119 at Low Pressure										
M7	N3044	35x12.50R18	3PE+2ST	32	3860	4550	8720	Y	0	1*
G5	N3016	LT275/65R20	2PE+2ST+2N	60	4434	5100	8998	Y	0	1*
G5	N3018	LT275/65R20	2PE+2ST+2N	60	4034	5100	7809	Y	0	1*
T1	N3023	LT375/50R18	3PE+2ST	50	2577	5100	4587	Y	0	1
T1	N3023	LT375/50R18	3PE+2ST	50	2870	5100	5508	N	0	1
T1	N3023	LT375/50R18	3PE+2ST	50	2811	5100	5488	Y	0	1
T1	N3023	LT375/50R18	3PE+2ST	50	2801	5100	5439	Y	0	1
T1	N3023	LT375/50R18	3PE+2ST	50	2869	5100	5538	Y	0	1
AVG	**N3023**	**LT375/50R18**	**3PE+2ST**	**50**	**2577**	**5100**	**5312**	**Y**	**0**	**5**

Note: 1.) NR = not required to pass requirement at pressure tested
* Could not be plugged.

Table 5.4 ASTM F414-06 Plunger Energy Test Results

Tire Type	Tire Number	Plunger Applications	Size	Construction	Test Pressure (psi)	Max Load (lbf)	FMVSS Minimum Energy (Inch-lbf)	Energy Inch-lbf	Pass requirement	Stopped before rupture	Rupture
ASTM F414-06											
D1	N3035	1	155R12	1PE+2ST	26	1528	1950	3995	Y	1	
D1	N3035	1	155R12	1PE+2ST	26	1453	1950	3612	Y	1	
D1	N3035	1	155R12	1PE+2ST	26	1489	1950	3952	Y	1	
D1	N3035	1	155R12	1PE+2ST	30	1559	1950	3986	Y		1
M9	N3026	1	P155/80R13	2PE+2ST	26	1592	1950	4216	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	26	1552	1950	4108	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	26	1577	1950	4167	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	26	1581	1950	4171	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	26	1583	1950	4187	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	30	1755	1950	4655	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	34	1862	1950	4934	Y	1	
M9	N3026	1	P155/80R13	2PE+2ST	38	1958	1950	4937	Y		1
C1	N3050	1	155/80R13	1 PE +2 ST	26	1133	1950	1989	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	26	1130	1950	2003	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	26	1079	1950	1818*	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	26	1888	1950	4991	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	26	1867	1950	4935	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	30	2012	1950	5333	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	34	2136	1950	5647	Y	1	
C1	N3050	1	155/80R13	1 PE +2 ST	38	2199	1950	5625	Y	1	
U1	N3014	1	P205/60R15	1PE + 2ST +1N	26	3289	2600	8047	Y		1
U1	N3014	1	P205/60R15	1PE + 2ST +1N	26	3253	2600	7980	Y		1
U1	N3014	1	P205/60R15	1PE + 2ST +1N	26	3247	2600	7824	Y		1
U1	N3014	1	P205/60R15	1PE + 2ST +1N	26	3259	2600	8011	Y		1
U1	N3014	1	P205/60R15	1PE + 2ST +1N	26	3217	2600	7940	Y		1
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	26	1784	2600	3153	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	26	1786	2600	3170	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	26	1696	2600	2857	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	26	2540	2600	6307	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	26	2546	2600	6367	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	30	2787	2600	6918	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	34	3023	2600	7513	Y	1	
Z1	N3041	1	275/45R20	2 PE + 2 ST + 2N	38	3228	2600	7965	Y		1
A1	N3002	1	275/45R20	2 PE + 2ST	32	2846	5200	7077	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	32	2836	5200	7053	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	32	2849	5200	7110	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	32	2857	5200	7121	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	32	2838	5200	7080	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	36	3059	5200	7600	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	40	3252	5200	8108	Y	1	
A1	N3002	1	275/45R20	2 PE + 2ST	44	3470	5200	8584	Y		1

Tire Type	Tire Number	Plunger Applications	Size	Construction	Test Pressure (psi)	Max Load (lbf)	FMVSS Minimum Energy (Inch-lbf)	Energy Inch-lbf	Pass requirement	Stopped before rupture	Rupture
ASTM F414-06 at Low Pressure											
M8	N3008	1	305/35ZR24	2PE +2ST +1P	26	2219	5200	4719	NR	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	26	2234	5200	4750	NR	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	26	2235	5200	4757	NR	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	26	2232	5200	4753	NR	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	26	2237	5200	4762	NR	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	30	2466	5200	5252	Y	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	34	2679	5200	5694	Y	1	
M8	N3008	1	305/35ZR24	2PE +2ST +1P	38	2586	5200	5000	N		1
Y1	N3028	1	305/35R24	2PE+2ST+2N	26	2042	5200	3041	NR	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	26	2062	5200	3886	NR	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	26	2053	5200	3866	NR	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	26	2070	5200	3891	NR	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	26	2234	5200	4202	NR	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	30	2429	5200	4578	NR	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	34	2634	5200	4957	N	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	38	2847	5200	5365	Y	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	42	3060	5200	5770	Y	1	
Y1	N3028	1	305/35R24	2PE+2ST+2N	48	3227	5200	6084	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	26	2724	5200	6329	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	26	2713	5200	6290	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	26	2726	5200	6361	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	26	2696	5200	6230	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	26	2696	5200	6277	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	30	2902	5200	6716	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	34	3200	5200	7403	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	38	3368	5200	7852	Y	1	
K1	N3020	1	305/40R23	2PE+2ST+2N	42	3495	5200	7868	Y		1

Note: 1.) NR = not required to pass requirement at pressure tested.

5.2 FMVSS No. 109 and 119 Results

Twelve tire models were tested to the FMVSS No. 109 and No. 119 test conditions. All of the tires reached the required energy level before bottom-out or rupture occurred. Of these 12 tires, 8 bottomed-out before being ruptured, and 4 ruptured. None of the tires would have failed the FMVSS No. 109 or 119 requirements. Complete graphs can be found in Appendix 1 and 3.

5.3 FMVSS No. 109 and 119 at Low Pressure Results

Three passenger and three light truck models were tested using a lower-than-FMVSS-specified pressure. A second tire of one passenger model (K1) and one light truck tire model (G5) were tested, resulting in a total of eight tests. Six of the tests met the FMVSS requirement at the low pressure. Tire models Y1 (N3028) and M8 (N3008) did not reach the required energy at 26 psi (Figure 5.2 and Figure 5.1) before bottom-out occurred. Normal testing for these models would have been at 32 psi. All four light truck tires ruptured before rim bottom-out, while none of the four passenger tires ruptured. The taller light truck tires have much more available plunger travel before bottom-out, which may explain these results. Complete graphs can be found in Appendix 2.

5.4 ASTM F414-06 Results

The six passenger tires tested to ASTM F414-06 reached the FMVSS minimum breaking energy level before bottom-out or rupture occurred. Five of those six tires also ended in rupture, but four of the five required the pressure to be increased before rupture occurred before bottoming-out. The increase in pressure allows a much better chance of building energy to passing the FMVSS minimum requirement before running out of travel (Figure 5.1, Figure 5.2, Figure 5.3 are good examples). The results can be found in Appendix 3.

5.5 ASTM F414-06 With Low Starting Pressures Results

Tests on three passenger tires were also conducted with ASTM F414-06 using a lower-than-specified pressure at the start of testing. One tire (N3008) did not did not reach the required energy level before bottoming-out in its five test runs at 26 psi. Three more runs were conducted with +4 psi pressure increments for each test. The first and second pressure increases, or 30 and 34 psi, generated enough breaking energy to meet FMVSS minimum requirements. However, the test at the third pressure of 38 psi resulted in the tire rupturing before meeting the minimum energy requirement (Figure 5.1). This was a significant finding, because it suggests that extrapolations of energy levels at lower pressures may not always be predictive of a test at a higher pressure. Another tire (N3028) did not reach the required energy level before bottoming-out in its five test runs at 26 psi. The tire generated increasingly higher energies with each incremental test pressure, eventually reaching the required FMVSS minimum energy in the 38, 42, and 46-psi test runs without any ruptures (Figure 5.2). The final tire (N3020) exceeded the minimum energy requirement on all 26-psi test runs, and also continued to generate higher average energies with each incremental pressure increase (Figure 5.3).

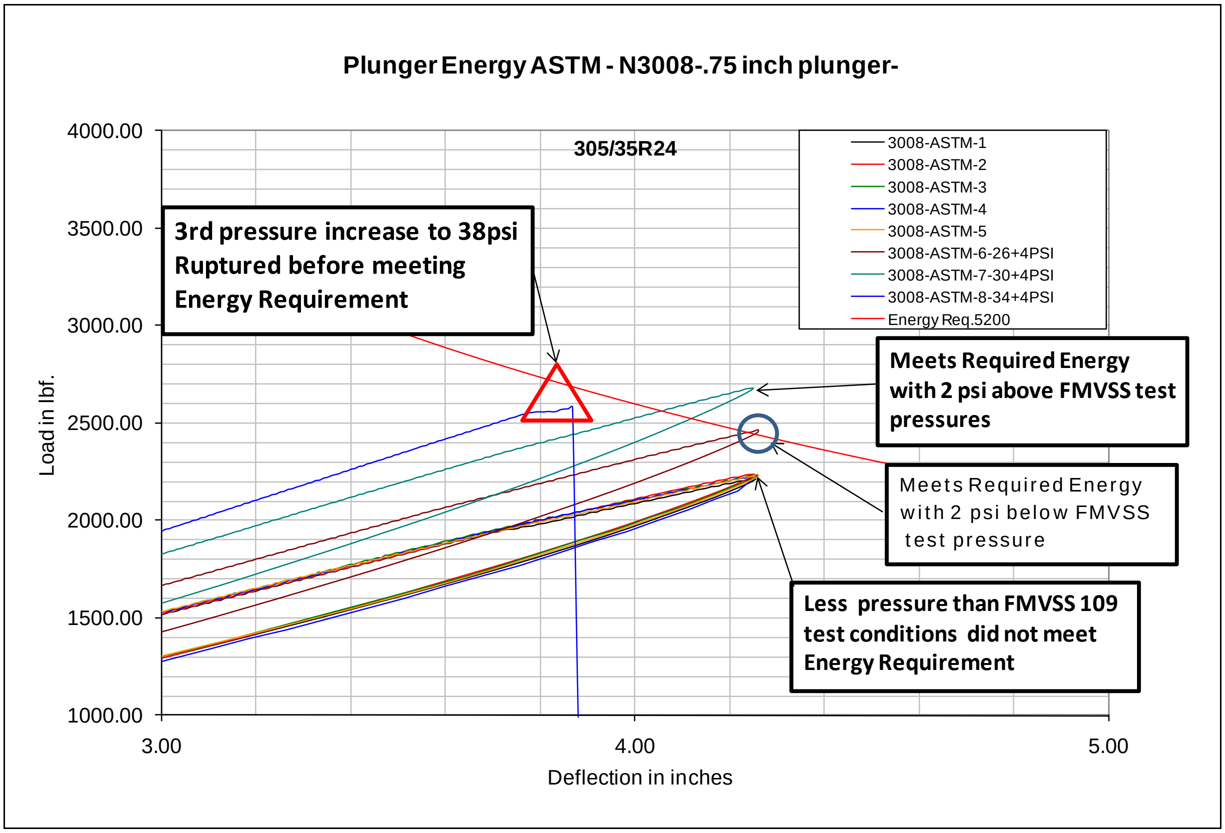

Figure 5.1 Tests of Tire M8-N3008

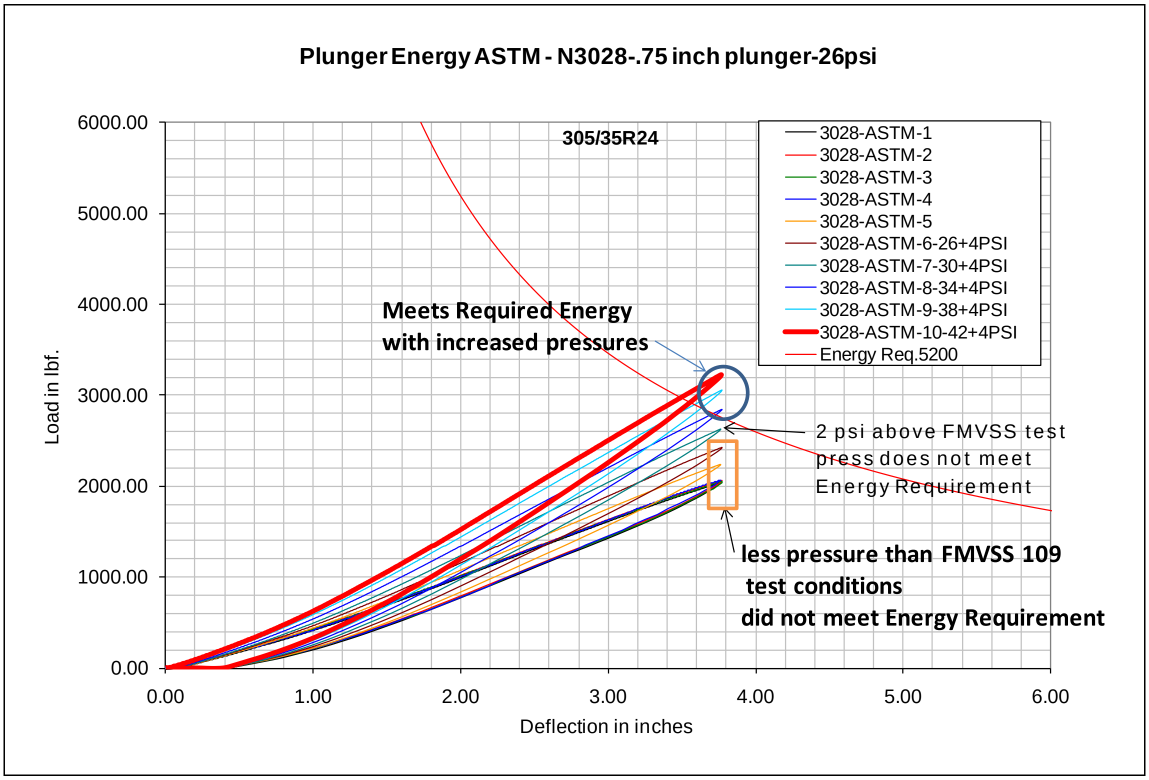

Figure 5.2 Tests of Tire Y1-N3028

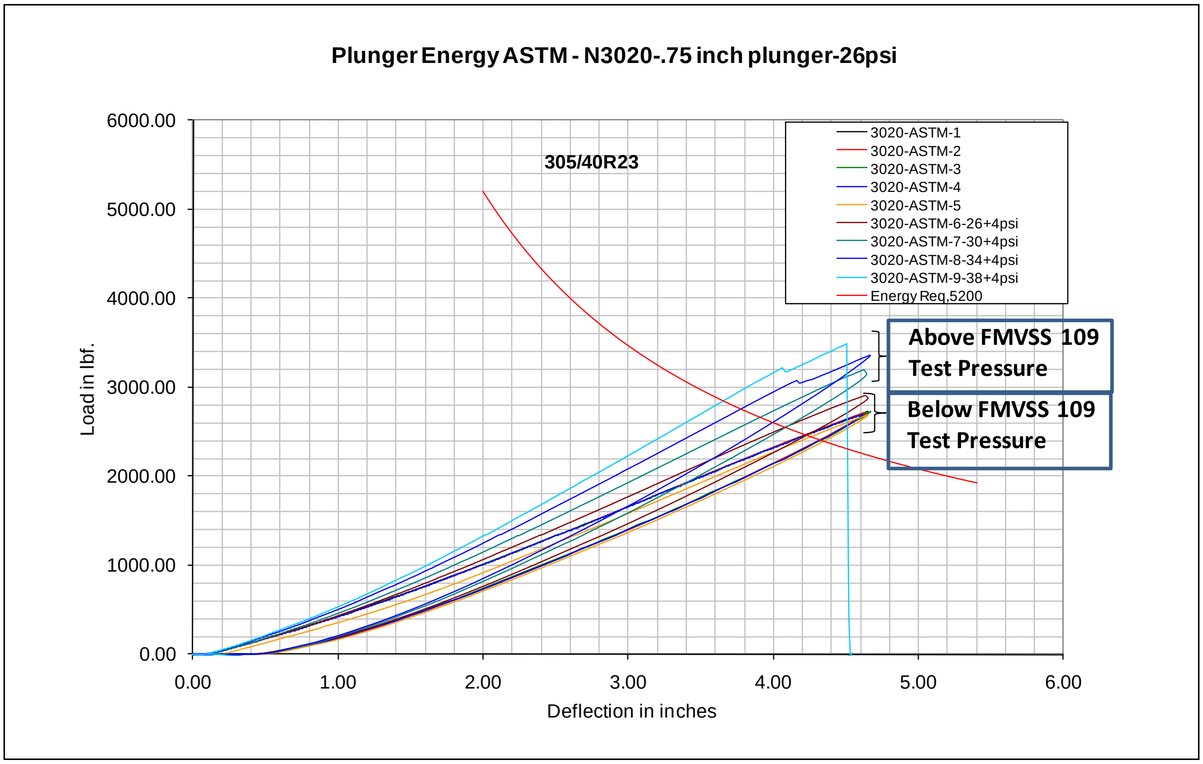

Figure 5.3 Tests of Tire K1-N3020

5.6 Crown Plunger Strength Summary

This report contains the results from 146 test runs designed to study the major variables in the FMVSS No. 109, No. 119, and ASTM F414-06 Plunger Energy Test. A total of 4 blocks of comparisons were possible from the 28 tests completed on 20 tires. Twelve comparisons were completed to evaluate FMVSS Nos. 109 and 119. Nine comparisons were completed to evaluate the ASTM F414-06 test standard. Ten comparisons were completed to determine the effects of pressure on the plunger energy test results. All tests were used to evaluate the likelihood of bottoming out with different sizes and profiles of tires.

5.7 Crown Plunger Strength Conclusions

5.7.1 Strength Test

The comparison between the FMVSS versus the ASTM test methods yielded consistent results. Regardless of the test method used, all of the tires tested at the normal test pressure exceeded the FMVSS No. 109 or 119 minimum breaking energy requirements.

Twelve tires were tested to the FMVSS No. 109 and No. 119 test conditions. All the tires reached the required breaking energy level before bottoming out or being ruptured. Of these 12 tires, 8 bottomed-out before being ruptured and 4 ruptured. Including the six tires tested to ASTM F414-06, and using only the first five data points (before increasing the pressure), five of the six bottomed-out and one was ruptured. In the overall group of 18 tires subjected to crown strength testing, 13 tires bottomed-out and 5 ruptured after achieving the required minimum breaking energy value.

5.7.2 Rupture Versus Bottom-Out

There were 117 of the 146 crown strength test runs (80%) that resulted in bottom-out condition. With the introduction of lower profile tire designs, many tires will bottom-out before the force and penetration become great enough to cause rupture. In tests with some of these lower profile tire it was not possible to rupture the tire before reaching a bottom-out condition without increasing the pressure.

5.7.3 Effect of Inflation Pressure

The lower inflation pressures used in this testing for passenger and light truck tires confirms that lower pressures could decrease the possibility of passing the FMVSS requirement or increase the chance of bottoming out. However, it also showed that in 7 of the 11 of these cases the tires still met or exceed the FMVSS requirements even when tested at the lower pressure.

Another effect of pressure observed was that as the pressure was increased, the spring rate of the tire increased as well. This is expected as the increased pressure makes the compression of the tire tread more difficult. This effect was found not to be linear in all cases. The slope of the increase was also not consistent from tire model to tire model. See Figure 5.4 ASTM F414-06 - Maximum Energy/Travel (Spring Rate) Versus Inflation Pressure for a comparison of the result of pressure increases.

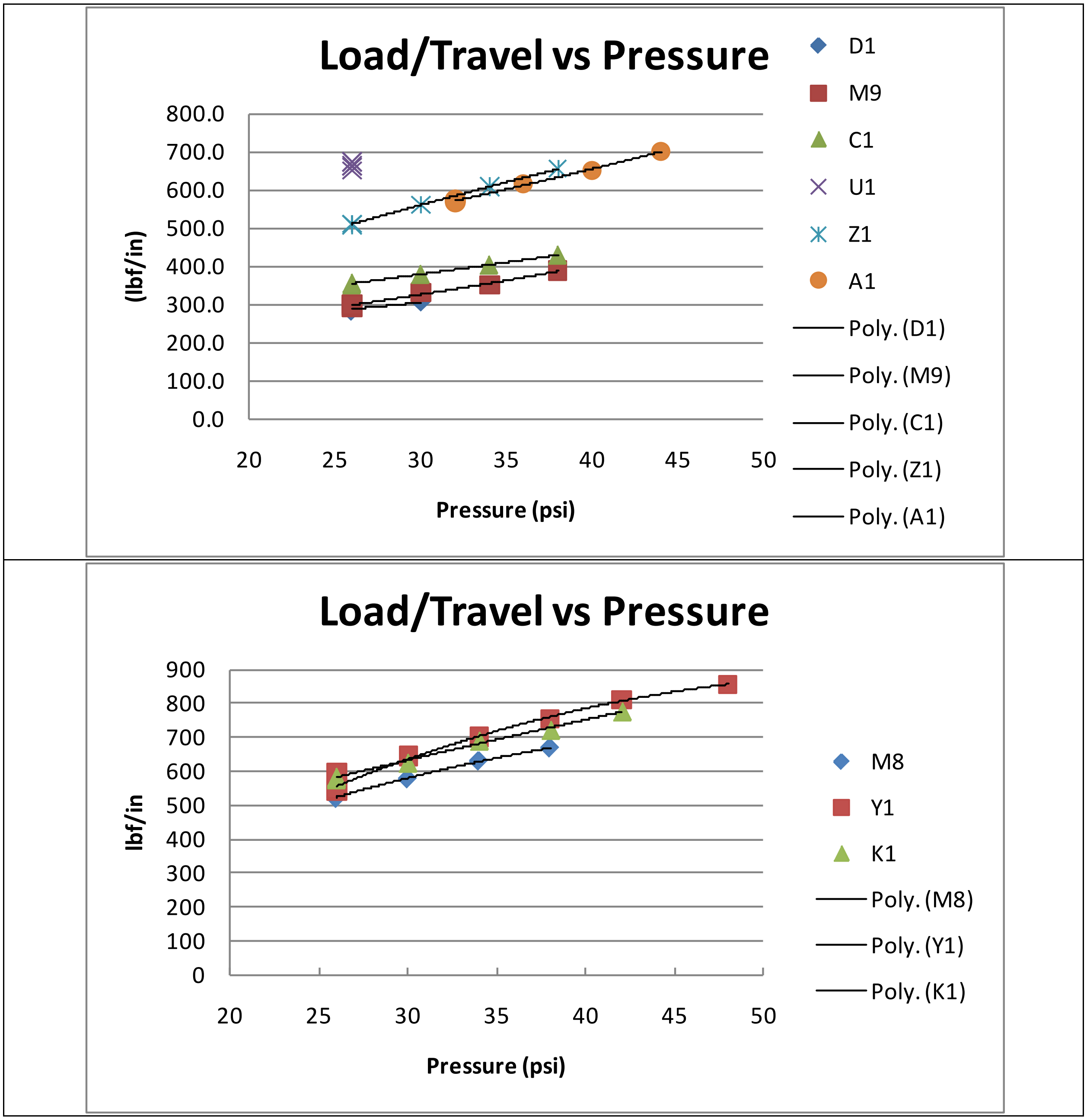

Figure 5.4 ASTM F414-06 - Maximum Energy/Travel (Spring Rate) Versus Inflation Pressure

5.7.4 ASTM F414-06

All tires tested to ASM F414-06 criteria exceeded the FMVSS No. 109 or No. 119 minimum breaking energy requirements. For all but one tire, it was necessary to increase pressure and complete additional plunger applications to transition from bottoming-out on the rim to rupture of the tire during the test.

5.7.5 Variability of ASTM F414-06

A brief statistical analysis found no difference in the energy values obtained for the first five tests by F414-06, FMVSS No. 109, or FMVSS No. 119.

5.8 Suggested Plunger Test Improvement

The authors suggest that to improve test accuracy using any tire plunger strength test method, that the load, displacement, and tire pressure be continuously recorded during the test. This will quantify the point at which the rupture or bottom-out occurred during the test. Modern electronic data acquisition and control allow the energy calculation to be done instantaneously, permitting the test operation to stop after the energy requirement is reached, possibly preventing damage to the plunger in tests that would unnecessarily be taken to bottom-out.

6.0 SIDEWALL PLUNGER STRENGTH TEST

6.1 Sidewall Strength Background

With the advent of larger rim diameters and lower-aspect-ratio tires, there are reports of more tires being damaged in the sidewall area due to impacts with curbs and potholes[22] [23] [24] The tire is usually either trapped between the rim and the object, or "bruised" by a pointed object, or both. This can break the body-ply cords and lead to a localized region of inter-laminar pressurization and separation. This damage is generally seen as a bulge (or "blister") in the sidewall in the vicinity of the impact, and may happen immediately or take some period of time to manifest after the initial impact. (Note that depressions in the sidewalls of radial tires are usually caused by overlapping cords during the construction process and are not a weak point on the tire but actually a stronger point. Open splices may show as a minor bulge, but are rarely noticed as they are only one to two cords (3-mm) wide. Neither of these cases was observed in this study.) The broken cords, visually seen as a bulge in the sidewall area create a weak area in the tire. This weak area becomes a safety concern as the tire may eventually blowout at the point of the broken cords. Also, sidewall bubbles that develop from impact damage cannot be repaired, resulting in replacement costs for the tire.

An idea was proposed to use the existing crown (tread) plunger strength test and bead unseat fixtures for a possible method of duplicating or creating the bulge or broken cords. Existing equipment was reconfigured to use the plunger to "bruise" the sidewall of the tire at four locations and measure the force to break the fabric cords of the sidewall. The fifth and final plunger application is taken to sidewall rupture or air loss. This method was used on a limited number of tires to examine the concept. The intent was to create and quantify the damage to several designs of tires. The force was applied to the sidewall of each of the tires with the same plunger as used for the FMVSS NO. 109 / 119 Strength test. Test criteria being specified in the test plan was to force the plunger into the sidewall of the tire until; 1) Breaking of the cords was heard, 2) The plunger ruptured the tire sidewall, or 3) Rubber to metal fixture contact was imminent. These three criteria would be used for stopping the penetration and the test. Investigation of possible quantification of the results included measurement of the force, penetration, resultant energy calculation, and measurement of the physical damage (bulge).

[22] "Low aspect ratio tires, with reduced sidewall height may be more susceptible to damage from potholes, road hazards, and other objects such as curbs. This is true for the wheels as well." Bridgestone Firestone North American Tire, LLC (2008, January). *Tire Maintenance, Safety and Warranty Manual – Replacement Market Passenger and Light Truck Tires.*

[23] "Engineers and safety experts say low-aspect-ratio tires -- which have shorter sidewalls -- are more vulnerable to road hazards, such as potholes and other obstructions that can test a tire's ability to flex at high speed, than their standard counterparts. Officials from Goodyear, Michelin, and Bridgestone, the three largest tire makers, all acknowledged in interviews that their low-aspect-ratio tires are more likely to be damaged by impacts in normal driving." Vartabedian, R. (2006, August 27). *Those sporty, low-aspect-ratio tires look great, but that might not help much over a pothole.* Los Angeles *Times*.

[24] "In addition, incidents of rim-pinch damage on the tire and rim impact damage on the wheel are also likely to increase as the tire's sidewall height is decreased. This sort of damage is very dependent upon the condition of the road surface in a given region and the speed limits in place on roads where potholes are prevalent." Daws, J. W., Larson, R. E., & Brown, J. C. (2005). The Impact of Plus-Sized Wheel/Tire Fitment on Vehicle Stability. Presented at the September 2005 Meeting of the Tire Society.

6.2 Equipment for Sidewall Plunger Strength Test

During the development of the sidewall plunger test, the tire and wheel were mounted on the base of the bead unseat fixture with the arm removed (see Figure 6.1).

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Figure 6.1 Bead Unseat Fixture with Arm Removed

The placement of the plunger was based on the positioning plan from the bead unseating test in ASTM F 2663-07. The location is at the FMVSS NO. 109 dimension "A" setting or 75 percent of the sidewall height, whichever is the least. It is the distance from the axle (rotational) centerline of the tire/wheel assembly and the centerline of the 19-mm (3/4-inch) plunger. The intended location for the plunger should be between the belt edges and the thinnest section of the sidewall. Figure 6.2 shows an example of the plunger placement. Table 5.3 of the prior section lists the tire and plunger placements.

Figure 6.2 Plunger Placement

6.3 Sidewall Plunger Strength Test Procedure

After positioning the plunger at the designated “A” Dimension on the tire sidewall, the test was run by forcing the plunger into the sidewall of the tire at 2.0 inches per minute (the same rate as the tread plunger strength test). As the plunger advanced into the sidewall of the tire, the load and deflection increased until an audible crack or cracking sound was heard, which was the sound of the sidewall cords rupturing. The operator was then to stop the test and inspect the tire. If the bulge was visible, measurements of the bulge were taken. Figure 6.3 shows an example of the bulge being measured. As the sidewall is not normally ruptured in this part of the test, following the measurement, the tire would be rotated 72 degrees, the air pressure checked and reset, and the next test run made, until four were completed. The fifth test was conducted until the plunger ruptured or damaged the tire in the plunger contact area. Figure 6.4 shows the typical load-deflection curve generated during the test. This figure also includes a photo of the plunger placement and deflection during the test. The tires selected and overall plan was to have samples of 1-ply, 2-ply, and 3-ply sidewall tires to allow a comparison of different sidewall constructions and possible resistance to “bruising.” The resistance to bruising is measured by the force to break the cords and the penetration. The energy thereby becomes the measure of strength. As in the plunger energy (strength) test, the energy is calculated by multiplying the force times the penetration and dividing by two:

W = [(FxP)/2]
Where W=Energy, inch-pounds;
F=Force, pounds; and P=Penetration, inches.

To determine the sidewall breaking energy value for the tire, average the five values obtained.

Also, two different sidewall materials were available, polyester and rayon. Although polyester is most widely used in the radial tire body or sidewall constructions, rayon is used by some manufacturers. Tests of this type may show if there is a strength difference between the two materials.

Figure 6.3 Sidewall Bulge Measurement

Photographs were taken at the start and end of each test. The data was recorded and assembled into Excel workbooks for each test. Complete results of the testing can be found in Table 6.1.

Table 6.1 Test Results Sidewall Plunger

Tire Type	Tire Number	Pressure (PSI)	Pressure (kPa)	Penetration (in)	Force at First Break (lbf)	Average Energy (In-lbf)	Measured Width of Bulge (mm)	Construction P = Passenger, LT = Light Truck / Body ply R = Rayon PE = Polyester
C1	3049	26.0	180	2.74	471	718.6	19	P / 1 PE
C1	3049	26.0	180	2.79	488		20	P / 1 PE
C1	3049	26.0	180	2.75	475		21	P / 1 PE
C1	3049	26.0	180	2.77	513		18	P / 1 PE
C1	3049	26.0	180	3.64	496		NA	P / 1 PE
D1	3034	26.0	180	2.92	438	740.0	18	P / 1 PE
D1	3034	26.0	180	3.05	467		18	P / 1 PE
D1	3034	26.0	180	2.95	452		19	P / 1 PE
D1	3034	26.0	180	2.93	440		20	P / 1 PE
D1	3034	26.0	180	4.31	498		NA	P / 1 PE
C6	3012	26.0	180	2.85	653	940.4	10.25	P / 2 R
C6	3012	26.0	180	2.97	686		11.31	P / 2 R
C6	3012	26.0	180	2.83	650		10.49	P / 2 R
C6	3012	26.0	180	2.61	640		11.79	P / 2 R
C6	3012	26.0	180	2.97	673		10.71	P / 2 R
K1	3019	26.0	180	2.82	909	1260.4	10.76	P / 2 PE
K1	3019	26.0	180	2.64	830		10.33	P / 2 PE
K1	3019	26.0	180	2.84	940		11.12	P / 2 PE
K1	3019	26.0	180	2.83	938		10.84	P / 2 PE
K1	3019	26.0	180	2.78	906		10.51	P / 2 PE
M7	3044	32	220	4.24	1048	2270.1	6.39	LT / 3 PE
M7	3044	32	220	4.22	1067		6.77	LT / 3 PE
M7	3044	32	220	4.30	1115		9.18	LT / 3 PE
M7	3044	32	220	4.25	1119		8.57	LT / 3 PE
M7	3044	32	220	4.07	1031		7.94	LT / 3 PE
Y1	3029	32	220	2.74	471	718.6	14	P / 2 PE
Y1	3029	32	220	2.79	488		5	P / 2 PE
Y1	3029	32	220	2.75	475		4	P / 2 PE
Y1	3029	32	220	2.77	513		6	P / 2 PE
Y1	3029	32	220	3.64	497		NA	P / 2 PE
T1	3023	50	340	3.64	967	1719.0	12.76	LT / 3 PE
T1	3023	50	340	3.55	948		NA	LT / 3 PE

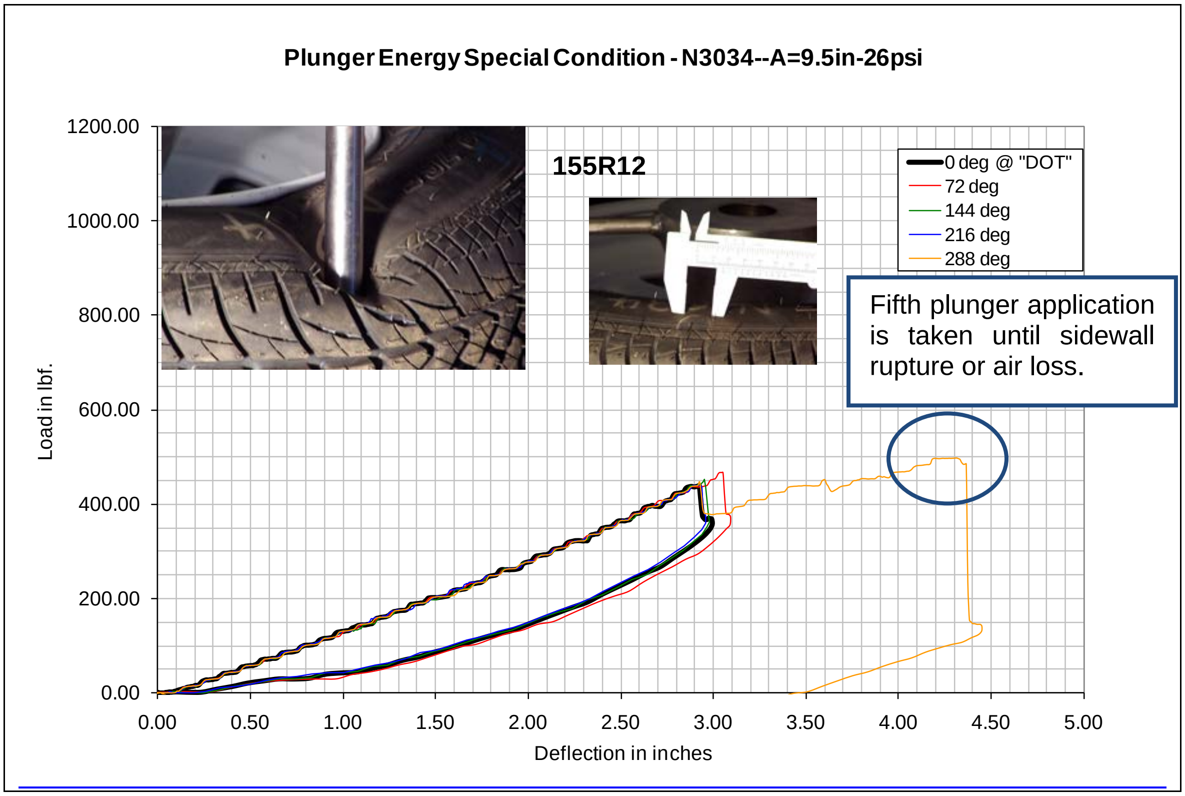


Figure 6.4 Load-Deflection Curve

6.4 Sidewall Plunger Strength Test Statistical Results

A statistical analysis was conducted on the results of the experimental sidewall plunger strength test results.

6.4.1 Canonical Correlations

Correlations range from -1 (perfect negative correlation) to +1 (perfect positive correlation) with zero being no correlation at all. Statistically significant values are shown as bolded values in Table 6.2.

Table 6.2 Pearson R Correlation Coefficients for Sidewall Plunger Measurements

Measurement	Plunger Position	Penetration	Bulge Width	Number of Plies	kPa
Force	**+ 0.60**	**+ 0.39**	**- 0.56**	**+ 0.85**	**+ 0.38**
Plunger Position		+ 0.09	**- 0.92**	**+ 0.78**	+ 0.26
Penetration			**- 0.36**	**+ 0.53**	+ 0.39
Bulge Width				**- 0.80**	- 0.40
Number of Plies					**+ 0.67**

The independent variables are plunger position (in relation to sidewall height), number of tire body plies, and test inflation pressure (kPa). Both plunger position and inflation pressure have a significant positive correlation with the number of plies, indicating probable covariance of the terms. Plunger position and inflation pressure have only a mild positive correlation.

The dependent variables are force, distance penetrated, and resulting sidewall bulge width. Bulge width has a moderate negative correlation to both force and distance traveled. Force and distance traveled have a moderate positive correlation with each other.

6.4.2 Linear Regression

Force

The primary variable that determines force is the number of plies.[25] The average force values for each ply rating are statistically different, as shown in Table 6.3.

Table 6.3 Mean Estimated Force for Sidewall Plunger Versus Number of Plies

F Value	Probability > F	R2	Number of Plies	Average Force Value (lbs)
340.3	< 0.0001	0.74	3	1042
			2	685
			1	474

There was a statistically significant difference between the force for the 2-ply polyester and the 2-ply rayon, with the polyester fabric generating higher force. The inflation pressure interacted with number of plies to influence force:

Force until cord break was decreased by approximately 2 to 6 pounds for each kPa of increased inflation (see Table 6.4). Apparent correlation of force with plunger position was a result of co-variance between plunger position and number of plies (see Figure 6.5).

[25] The number of plies is covariant with plunger position and inflation pressure. There is insufficient data to determine whether each has an independent effect.

Table 6.4 Linear Regression of Force Versus Number of Plies and Inflation Pressure (kPa)

Dependent Variable: Force

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	1578482.354	526160.785	62.62	<.0001
Error	28	235269.521	8402.483		
Corrected Total	31	1813751.875			

R-Square	Coeff Var	Root MSE	Force Mean
0.870286	13.15255	91.66506	696.9375

Source	DF	Type III SS	Mean Square	F Value	Pr > F
kPa*Plies	3	1578482.354	526160.785	62.62	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1550.433566	137.3108947	11.29	<.0001
kPa*Plies 1	-5.981298	0.7796511	-7.67	<.0001
kPa*Plies 2	-4.505437	0.7140090	-6.31	<.0001
kPa*Plies 3	-1.954928	0.5334240	-3.66	0.0010

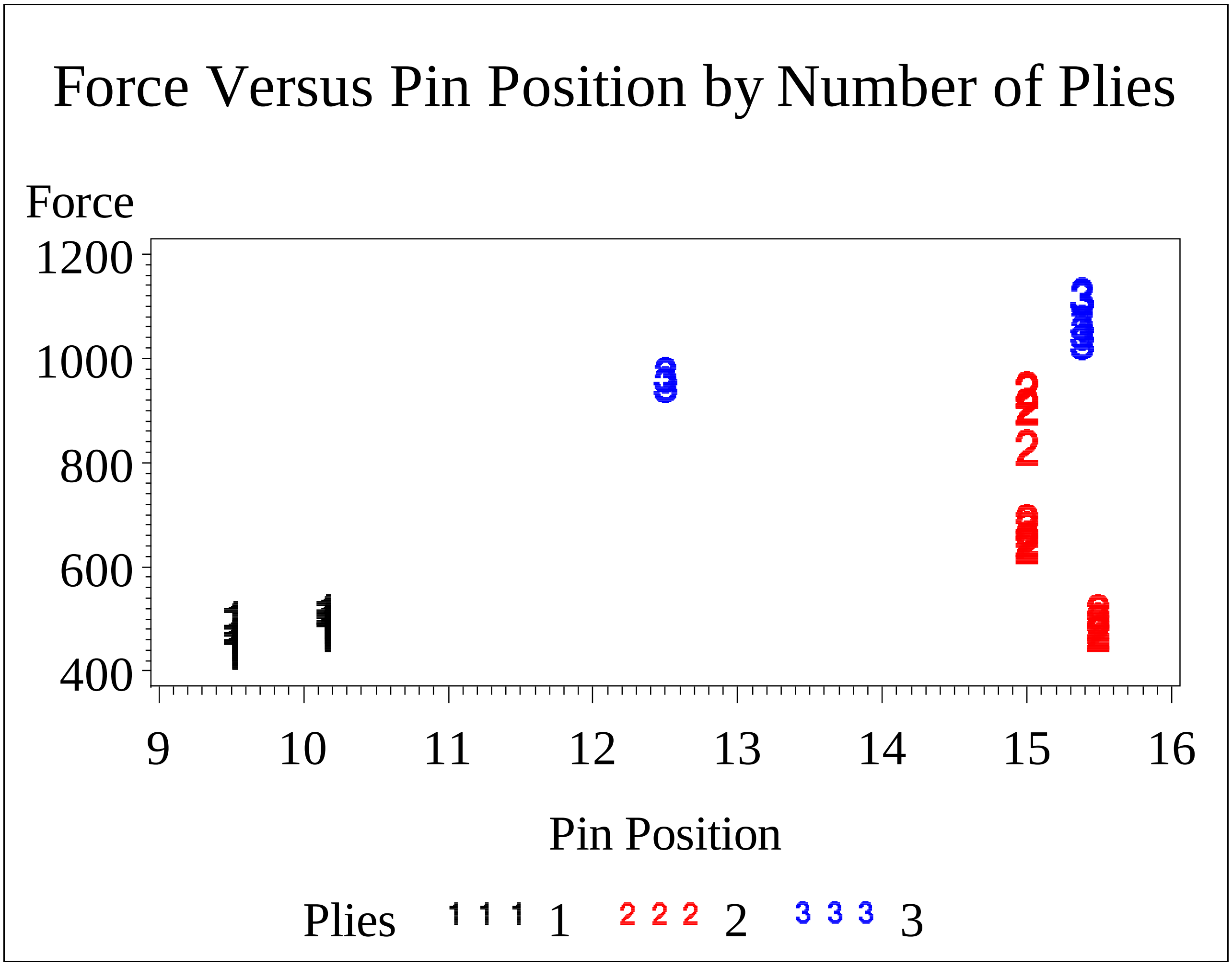


Figure 6.5 Force Versus Plunger Position: Illustrating Covariance With Number of Plies

Plunger Penetration

The penetration distance is primarily related to the number of plies, which is covariant with plunger position and inflation pressure. There is not sufficient data to separate the effects. Table 6.5 shows the results of the linear regression and the Duncan's multiple range test, indicating that the 1 and 2-ply constructions are not significantly different while the 3-ply construction has significantly higher penetration.

Table 6.5 Linear Regression of Force Versus Plunger Position (inches), Number of Plies, And Inflation Pressure (kPa)

```
        The GLM Procedure
Dependent Variable: Penetration
        Sum of
  Source     DF   Squares Mean Square  F Value  Pr > F
  Model    4 331.7490892 82.9372723 651.87  <.0001
  Error    28  3.5624108  0.1272290
  Uncorrected Total  32 335.3115000

    R-Square Coeff Var Root MSE  Penetration Mean
    0.660890 11.19582 0.356692  3.185938

  Source     DF Type III SS Mean Square  F Value  Pr > F
  Plunger*kPa     1 0.11249822 0.11249822  0.88  0.3551
  Plies    3 19.84360098 6.61453366 51.99  <.0001

          Standard
    Parameter  Estimate  Error  t Value  Pr > |t|
    Plunger*kPa   -0.000200952 0.00021370 -0.94 0.3551
    Plies 1 3.440203035 0.39422447  8.73 <.0001
    Plies 2 3.445462839 0.63429935  5.43 <.0001
    Plies 3 4.768257424 0.78761422  6.05 <.0001

     Duncan's Multiple Range Test for Penetration

     Alpha      0.05
     Error Degrees of Freedom   28
     Error Mean Square  0.127229
     Harmonic Mean of Cell Sizes 9.692308
     Number of Means   2   3
     Critical Range  .3319 .3487

    Means with the same letter are not significantly different.

    Duncan Grouping   Mean N  Plies
```

A 4.0386 7 3

B 3.0850 10 1
B
B 2.8553 15 2

Bulge Width

The width of the bulge is primarily a function of the number of plies, as shown by the linear regression results in Table 6.6 below. The Duncan's multiple range test indicates that the single-ply construction has a significantly larger bulge width, while the 2 and 3-ply constructions are not significantly different from each other. Plunger position is correlated to bulge width only because of its covariance with number of plies as shown in Figure 6.6 below.

Table 6.6 Linear Regression of Bulge Width Versus Number of Plies

Dependent Variable: Bulge

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	4712.853595	1570.951198	288.30	<.0001
Error	25	136.223405	5.448936		
Uncorrected Total	28	4849.077000			

R-Square	Coeff Var	Root MSE	Bulge Mean
0.799267	19.12685	2.334296	12.20429

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Plies	3	4712.853595	1570.951198	288.30	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Plies	3	4712.853595	1570.951198	288.30	<.0001

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Plies 1	19.12500000	0.82529814	23.17	<.0001
Plies 2	9.79357143	0.62386675	15.70	<.0001
Plies 3	8.60166667	0.95297221	9.03	<.0001

Duncan's Multiple Range Test for Bulge

Alpha 0.05
Error Degrees of Freedom 25
Error Mean Square 5.448936
Harmonic Mean of Cell Sizes 8.262295

Number of Means 2 3
Critical Range 2.365 2.485

Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	Plies
A	19.125	8	1
B	9.794	14	2
B			
B	8.602	6	3

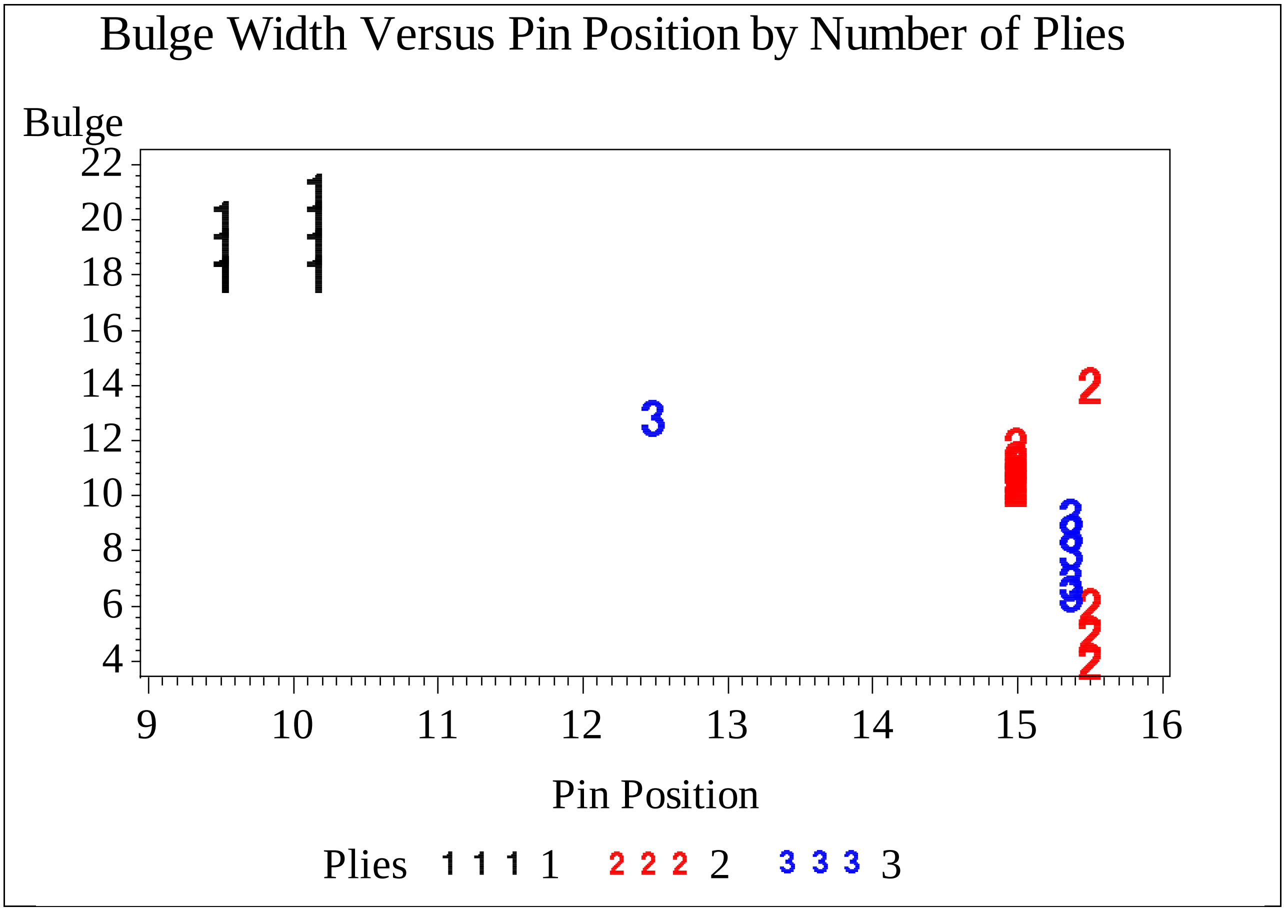


Figure 6.6 Bulge Width Versus Plunger Position and Number of Plies

6.5 Sidewall Plunger Strength Conclusions

The following was concluded from the statistical analysis of the tire sidewall plunger strength data.

6.5.1 Force or Energy

The force or energy reported for sidewall plunger testing is differentiated for the number of plies in the tire sidewall.

6.5.2 Plies

The single-ply tires have a greater bulge width (i.e., resultant cord spreading, cord breakage, and/or delamination) than the 2 or 3-ply sidewall tires.

6.5.3 Plunger Penetration

Plunger penetration is primarily related to the number of sidewall plies and is a covariant with the plunger position and inflation pressure.

6.5.4 Measurement

Sidewall plunger can provide a number value (energy or force) to quantify resistance of a tire to sidewall bruising or impact. However, in this experimental approach, the first four plunger applications for sidewall bruising rely on the operator stopping the test when an audible crack is heard, a potential source of test variation. The fifth plunger application applies force until ultimate rupture of the sidewall or air loss, which is less operator dependent.

6.5.5 Test Improvement

To improve test accuracy, tire pressure should be continuously recorded during the test. This will help quantify the point at which the cord break occurs, or if complete rupture/air loss occurred during the test.

BIBLIOGRAPHY

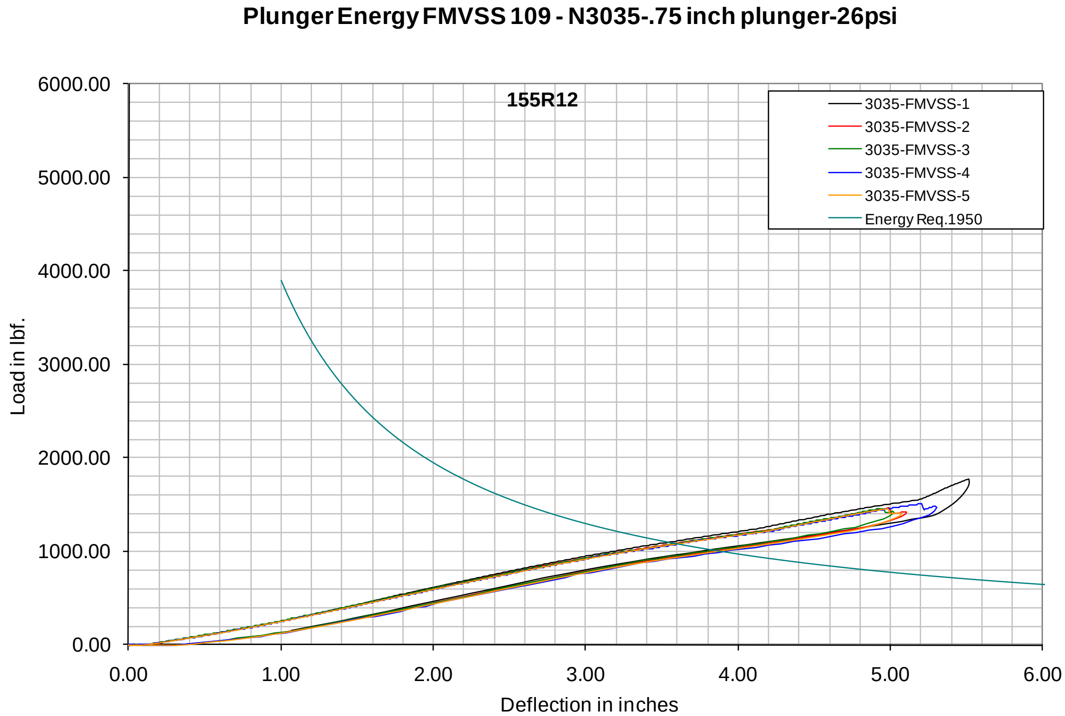
1. CFR 49 Part 571; Federal Motor Vehicle Safety Standards; Tires; Proposed Rule. March 5, 2002. Vols. Docket No. NHTSA-00-8011-0019.

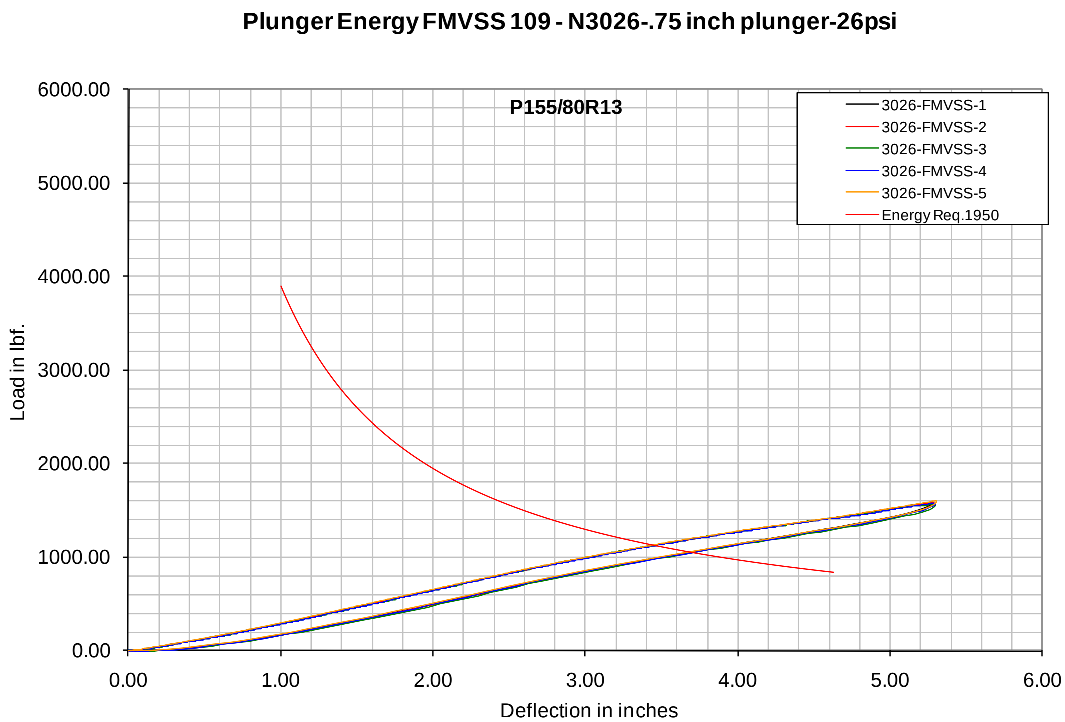
2. Risteen, W. H. (1967). *Report on the Development of the Initial Federal Motor Vehicle Safety Standards Issued January 31, 1967.* Washington, DC: National Traffic Safety Agency [sic; this was the name of a pre-cursor agency prior to the creation of NHTSA in 1970].

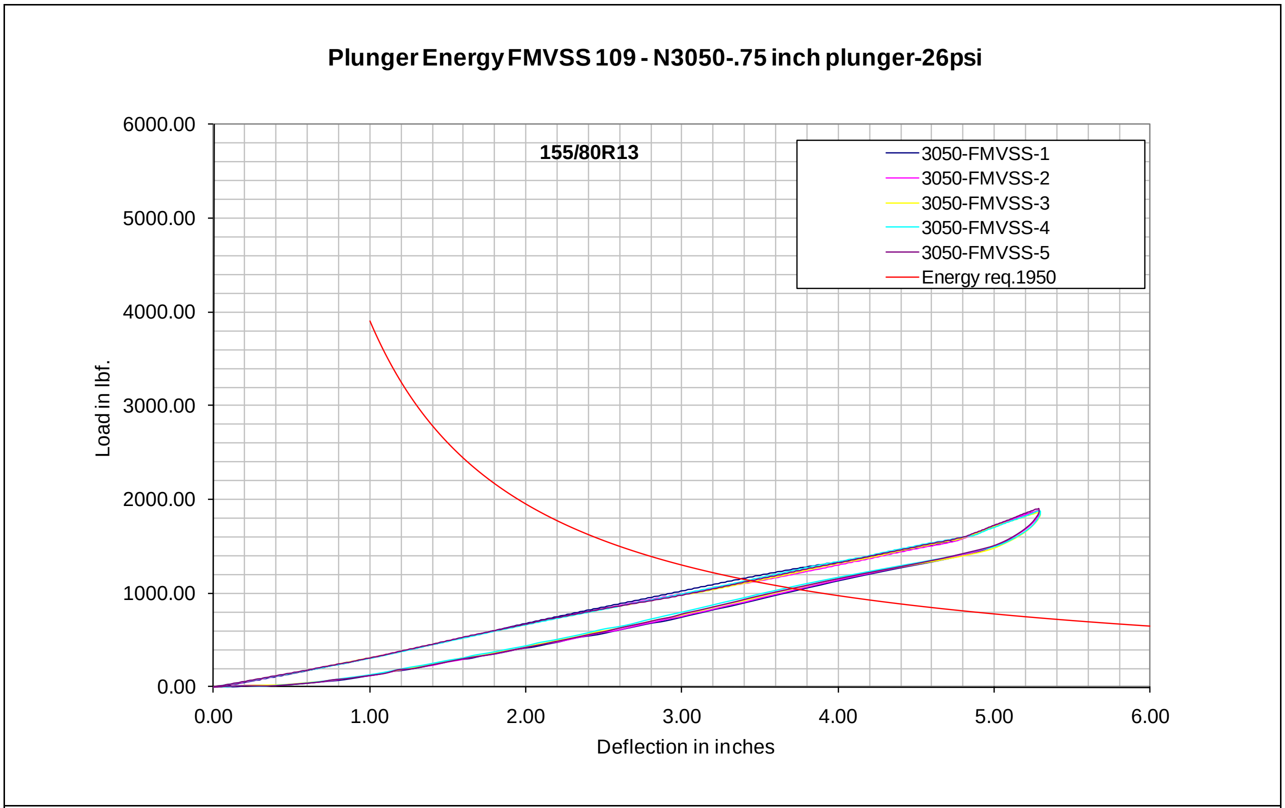
3. Gent, A. N., & Walter, J. D. (Eds.)**.** (2006, February). *The pneumatic tire.* (Report No. DOT HS 850 561). Washington DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/staticfiles/safercar/pdf/PneumaticTire_HS-810-561.pdf.

4. 49 CFT Part 571; Federal Motor Vehicle Safety Standards; Tires; Final Rule. Washington, DC : s.n., June 26, 2003. Vols. Docket No. NHTSA-03-15400-0001.

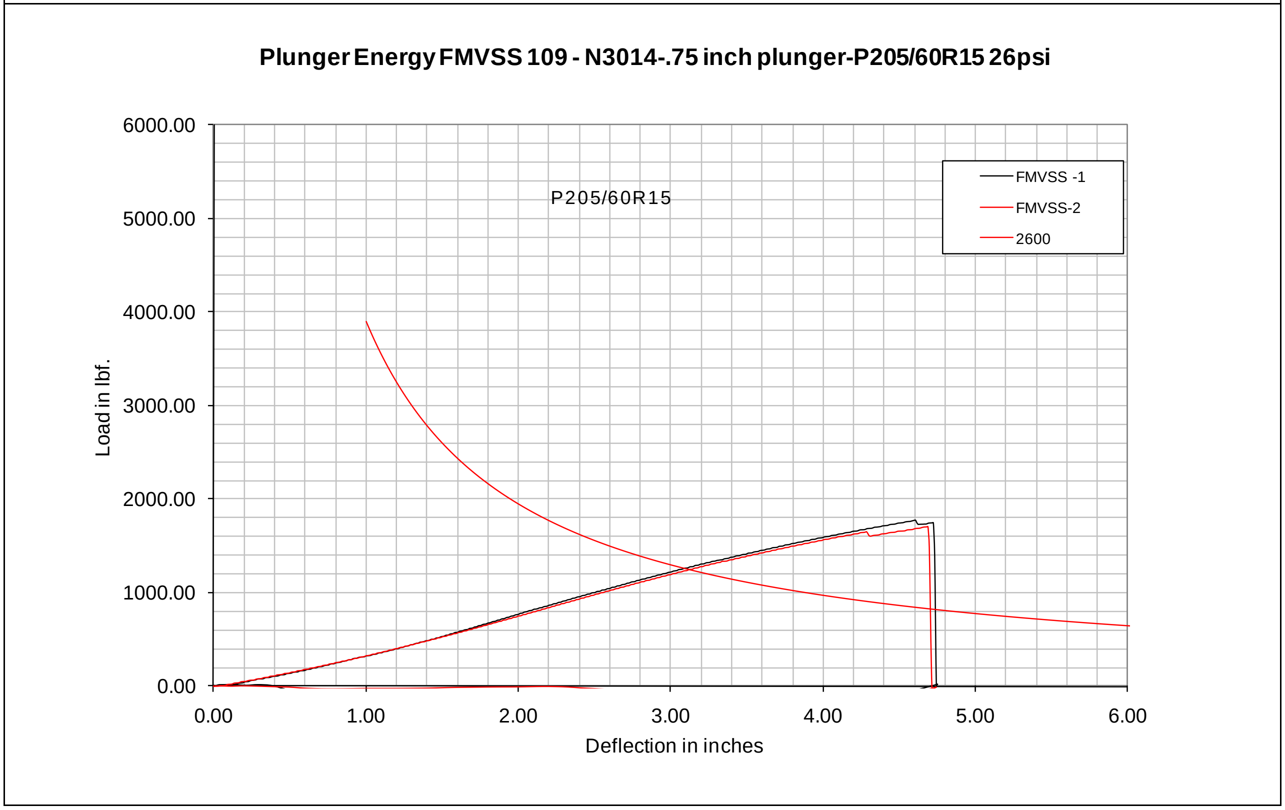
APPENDIX 1 FMVSS NOS. 109 AND 119 TESTS



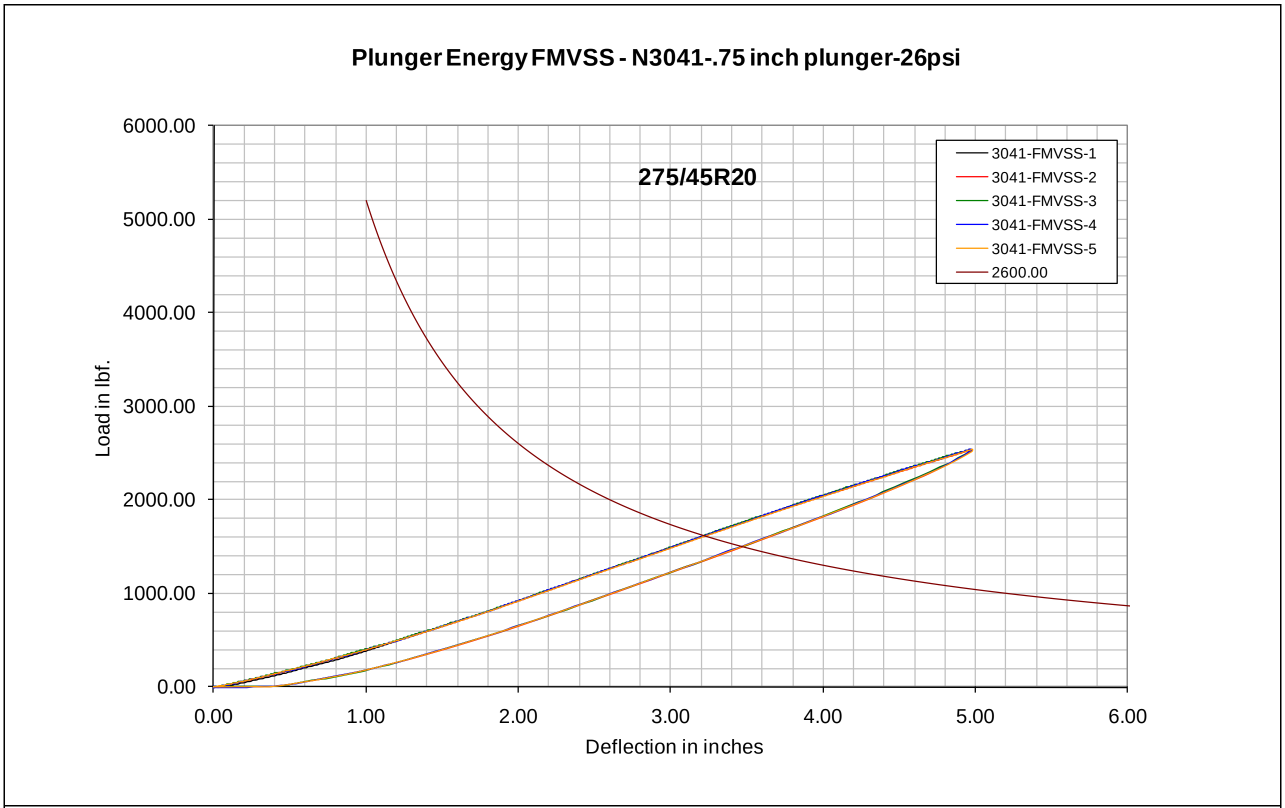




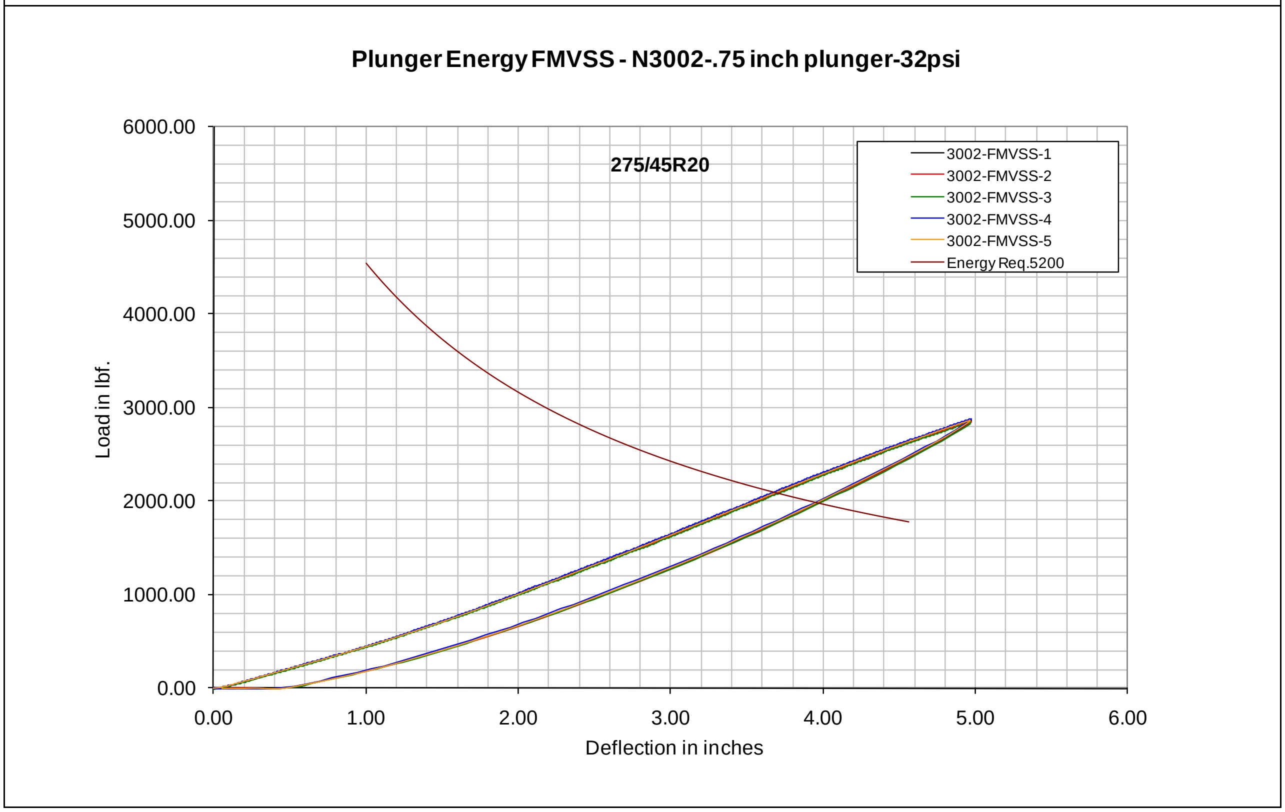
Plunger Energy FMVSS 109 - N3050-.75 inch plunger-26psi
155/80R13
3050-FMVSS-1
3050-FMVSS-2
3050-FMVSS-3
3050-FMVSS-4
3050-FMVSS-5
Energy req.1950
Load in lbf.
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches



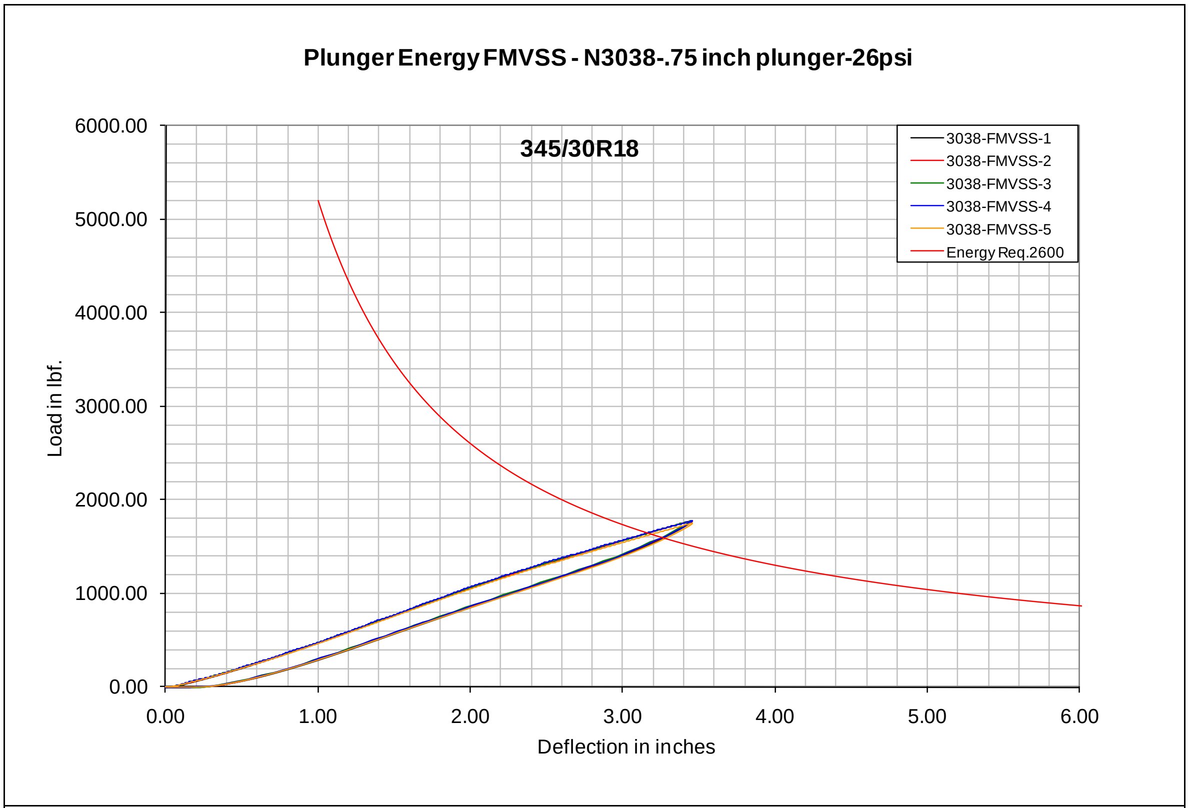
Plunger Energy FMVSS 109 - N3014-.75 inch plunger-P205/60R15 26psi
P205/60R15
FMVSS -1
FMVSS-2
2600
Load in lbf.
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches

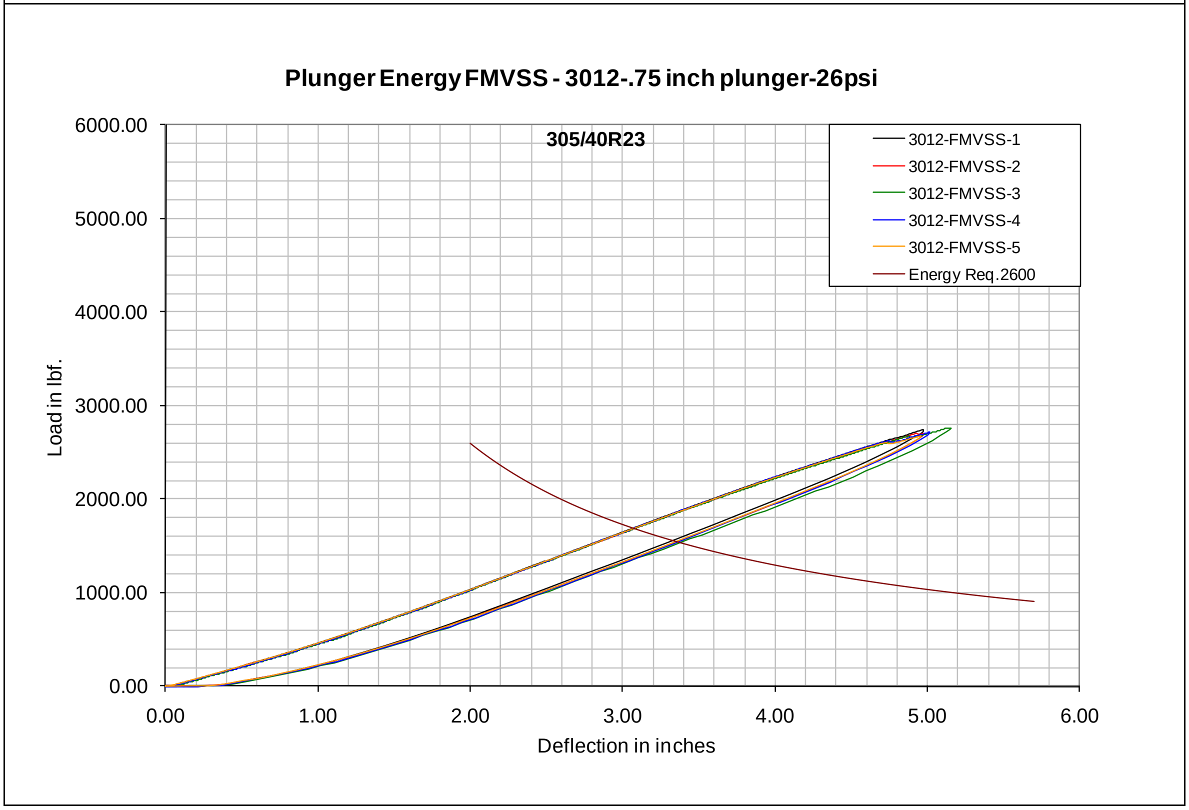


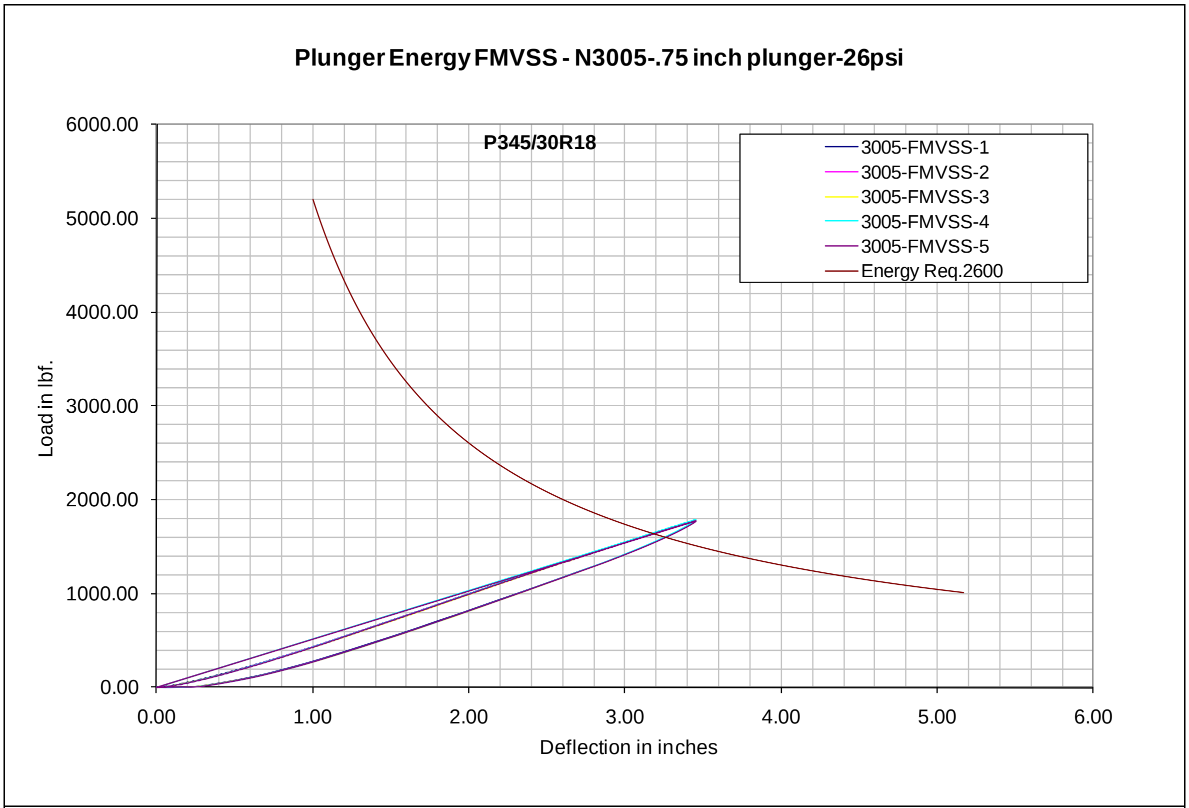
Plunger Energy FMVSS - N3041-.75 inch plunger-26psi
275/45R20
3041-FMVSS-1
3041-FMVSS-2
3041-FMVSS-3
3041-FMVSS-4
3041-FMVSS-5
2600.00
Load in lbf.
Deflection in inches
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

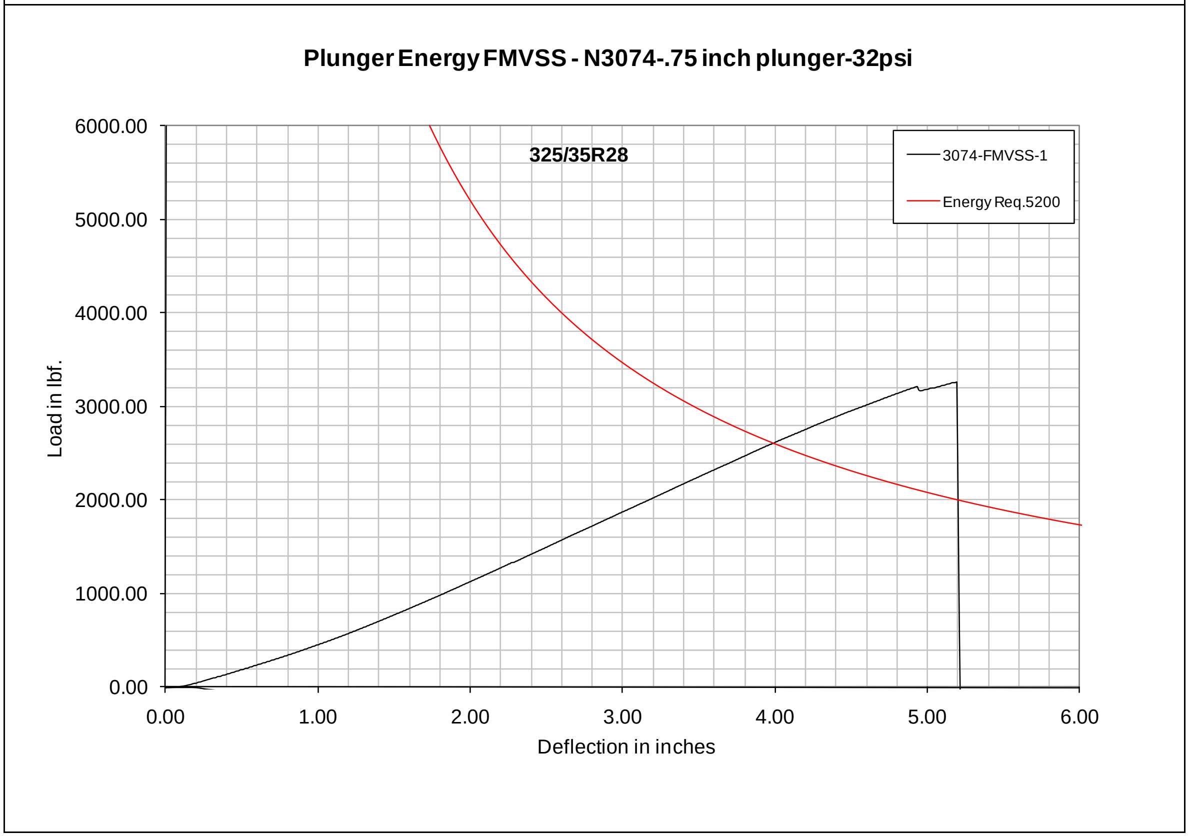


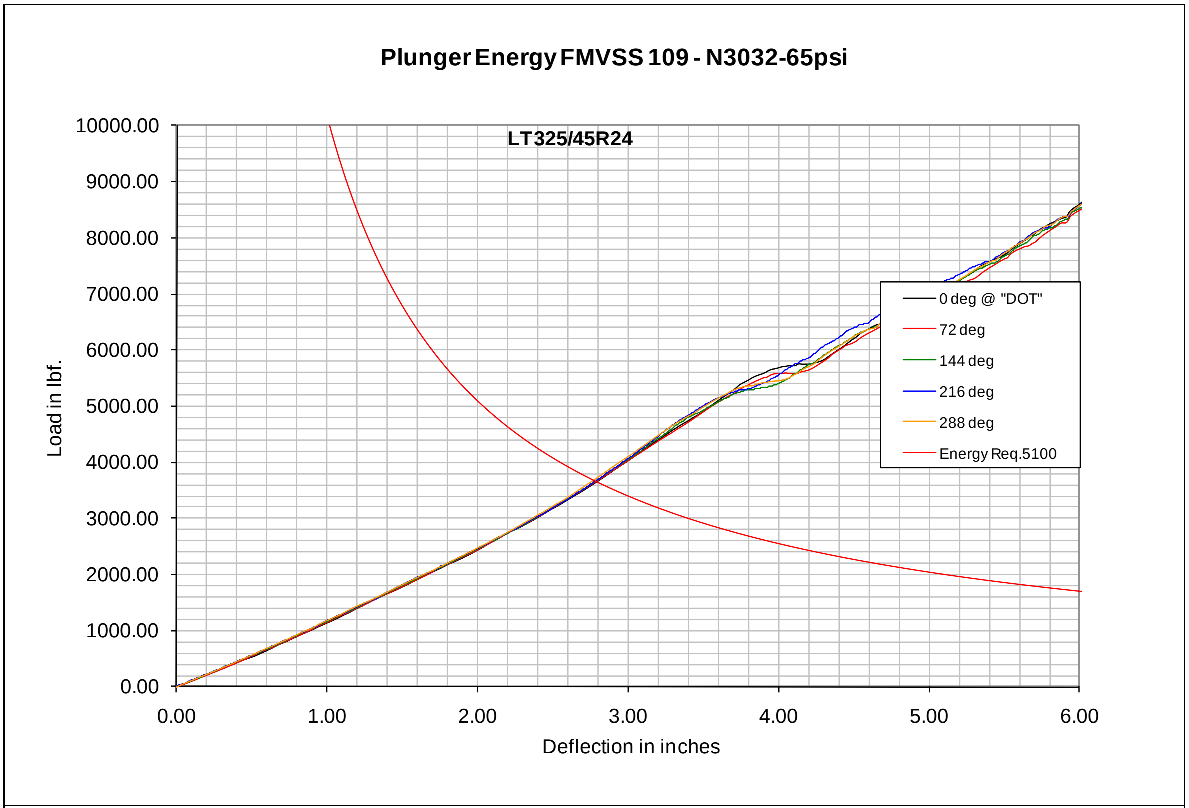
Plunger Energy FMVSS - N3002-.75 inch plunger-32psi
275/45R20
3002-FMVSS-1
3002-FMVSS-2
3002-FMVSS-3
3002-FMVSS-4
3002-FMVSS-5
Energy Req.5200
Load in lbf.
Deflection in inches
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
6000.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

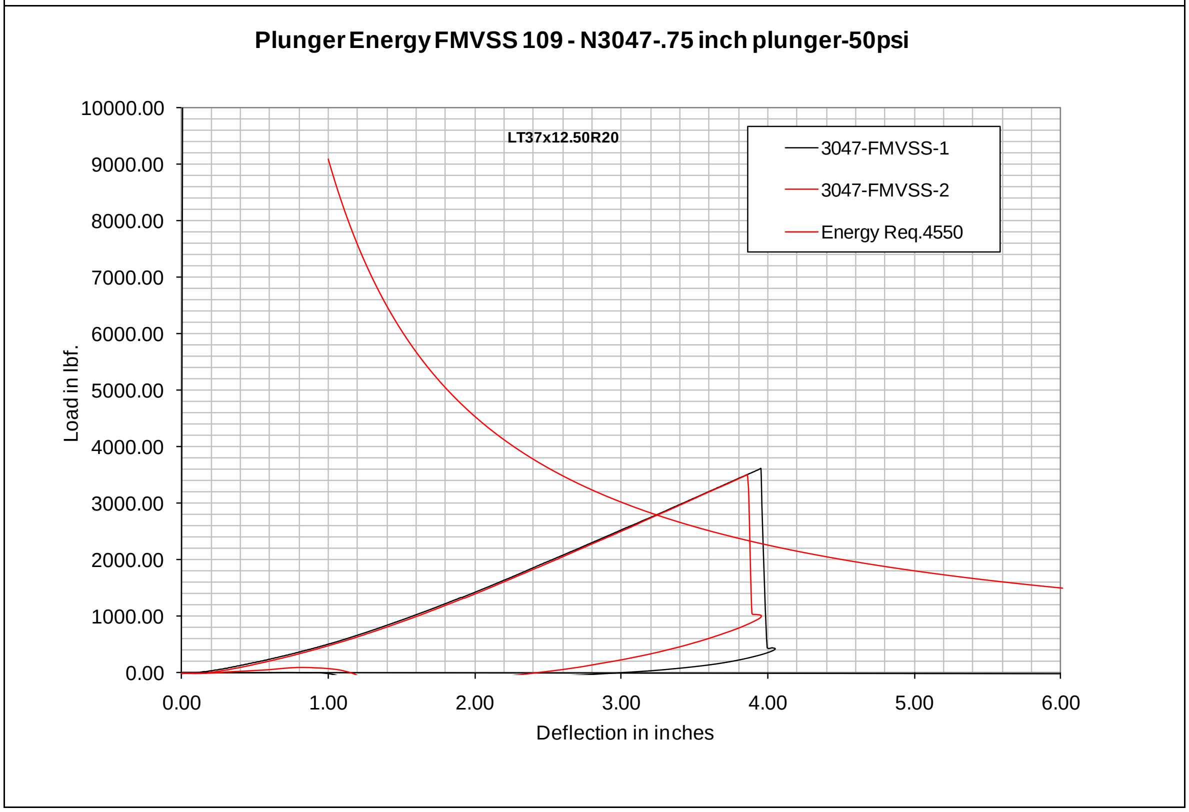

Plunger Energy FMVSS - N3038-.75 inch plunger-26psi
345/30R18
3038-FMVSS-1
3038-FMVSS-2
3038-FMVSS-3
3038-FMVSS-4
3038-FMVSS-5
Energy Req.2600
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00


Plunger Energy FMVSS - 3012-.75 inch plunger-26psi
305/40R23
3012-FMVSS-1
3012-FMVSS-2
3012-FMVSS-3
3012-FMVSS-4
3012-FMVSS-5
Energy Req.2600
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

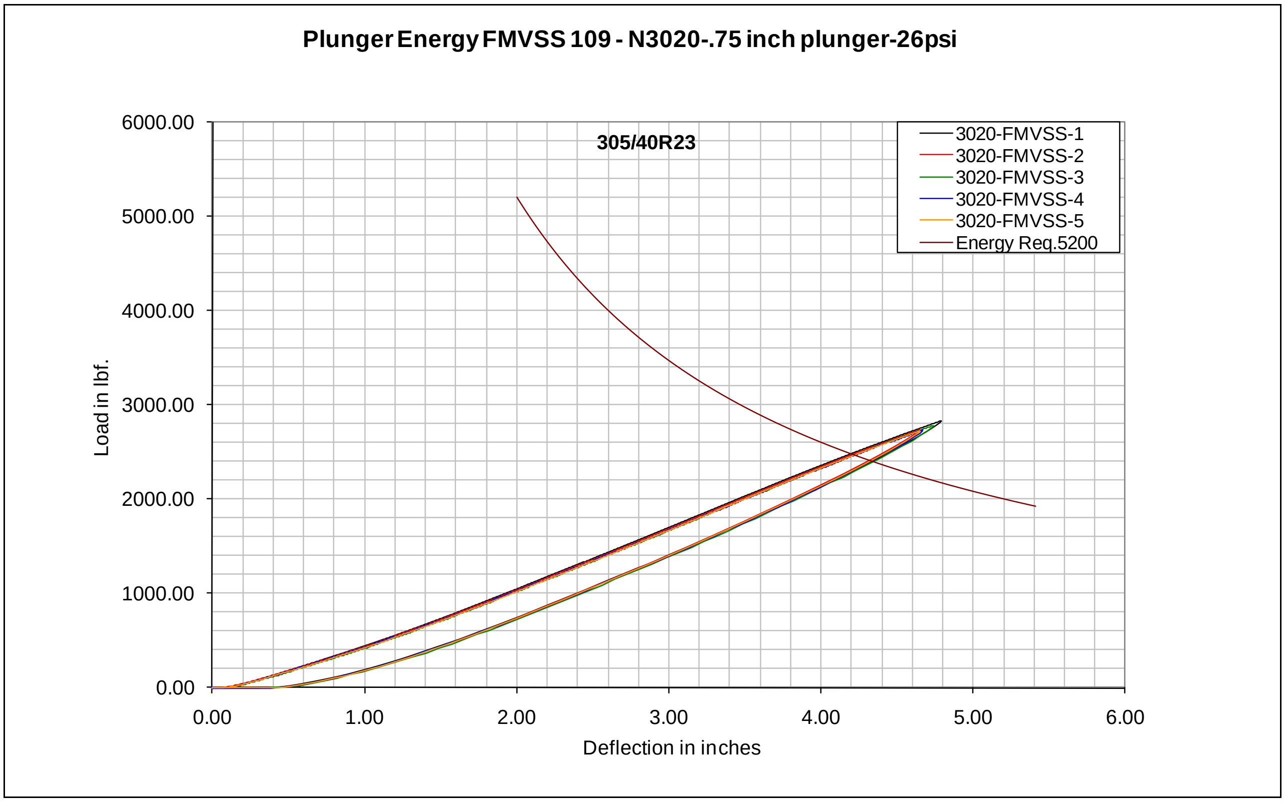

Plunger Energy FMVSS - N3005-.75 inch plunger-26psi
P345/30R18
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
Load in lbf.
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches
3005-FMVSS-1
3005-FMVSS-2
3005-FMVSS-3
3005-FMVSS-4
3005-FMVSS-5
Energy Req.2600

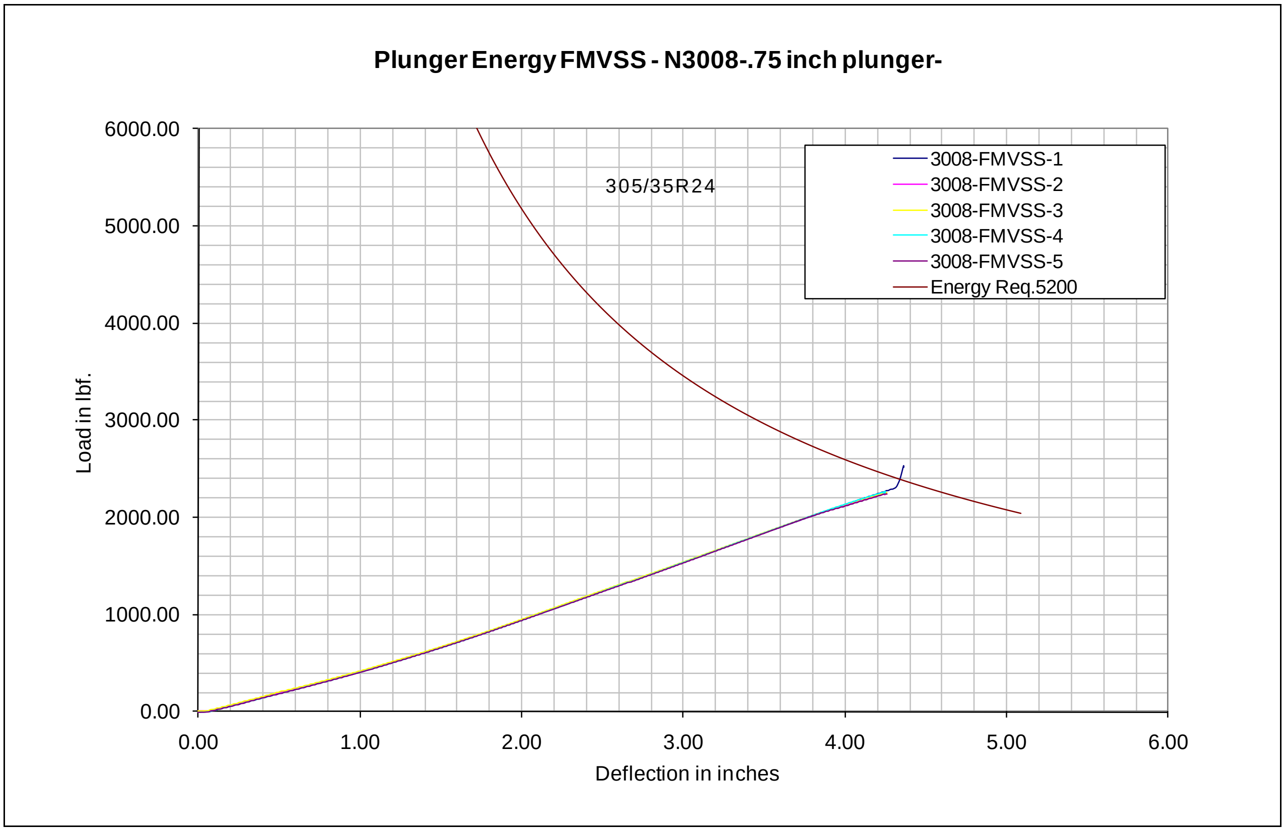

Plunger Energy FMVSS - N3074-.75 inch plunger-32psi
325/35R28
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
Load in lbf.
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches
3074-FMVSS-1
Energy Req.5200

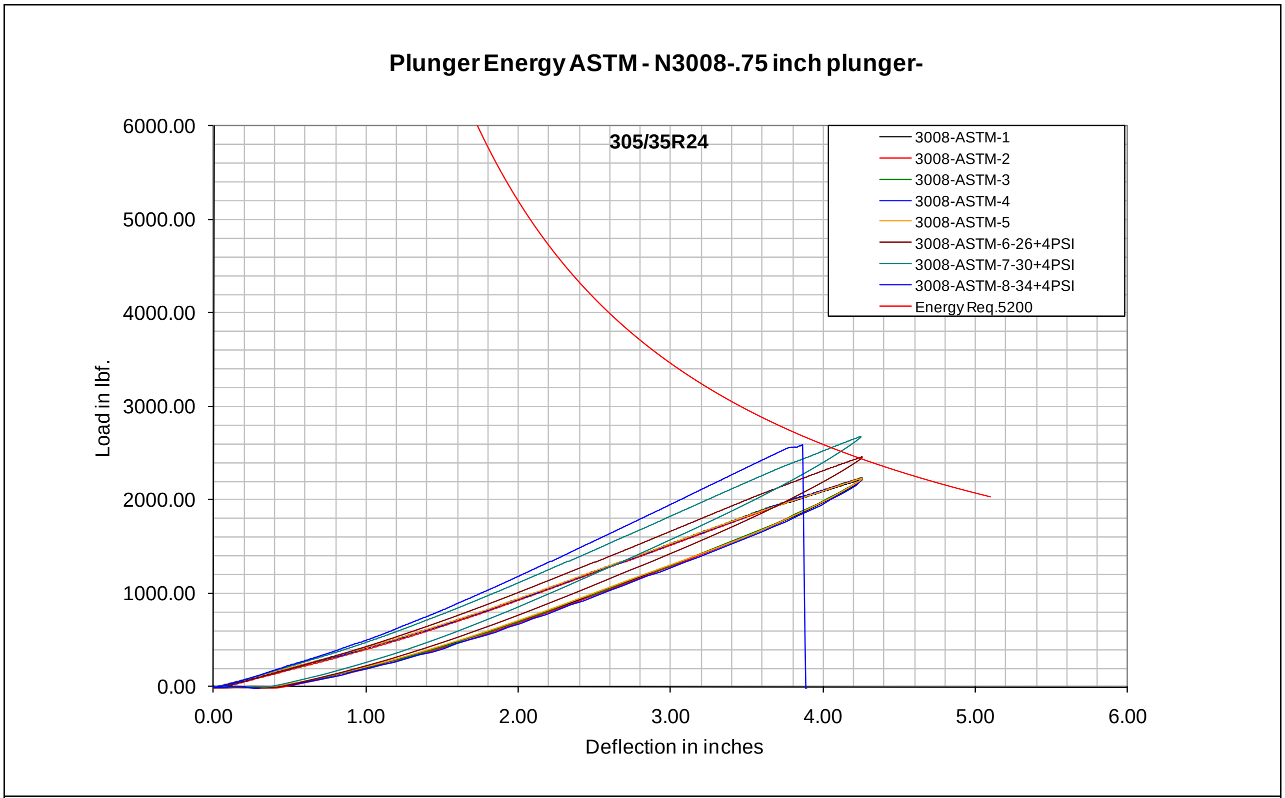

Plunger Energy FMVSS 109 - N3032-65psi
LT325/45R24
Load in lbf.
10000.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches
0 deg @ "DOT"
72 deg
144 deg
216 deg
288 deg
Energy Req.5100

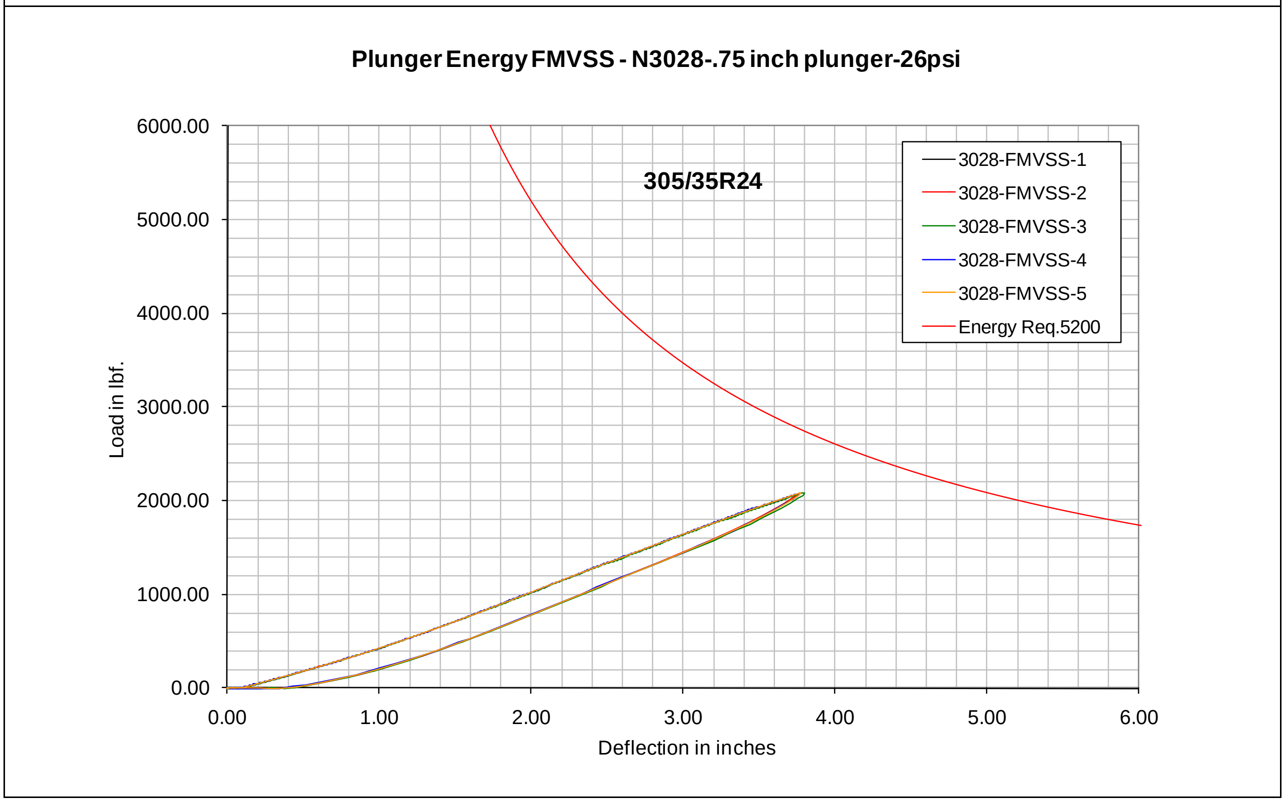

Plunger Energy FMVSS 109 - N3047-.75 inch plunger-50psi
LT37x12.50R20
Load in lbf.
10000.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches
3047-FMVSS-1
3047-FMVSS-2
Energy Req.4550

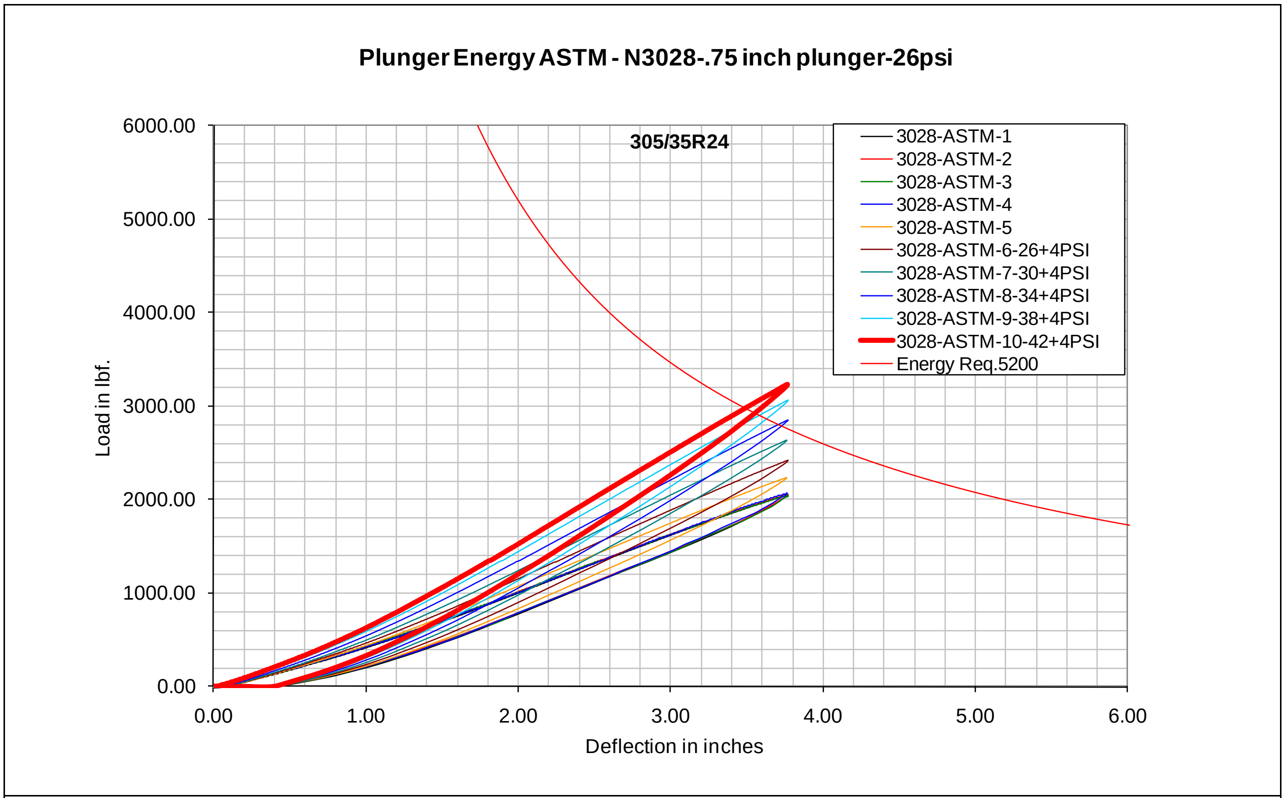
APPENDIX 2 FMVSS NOS. 109 AND 119 TESTS AT LOW PRESSURE

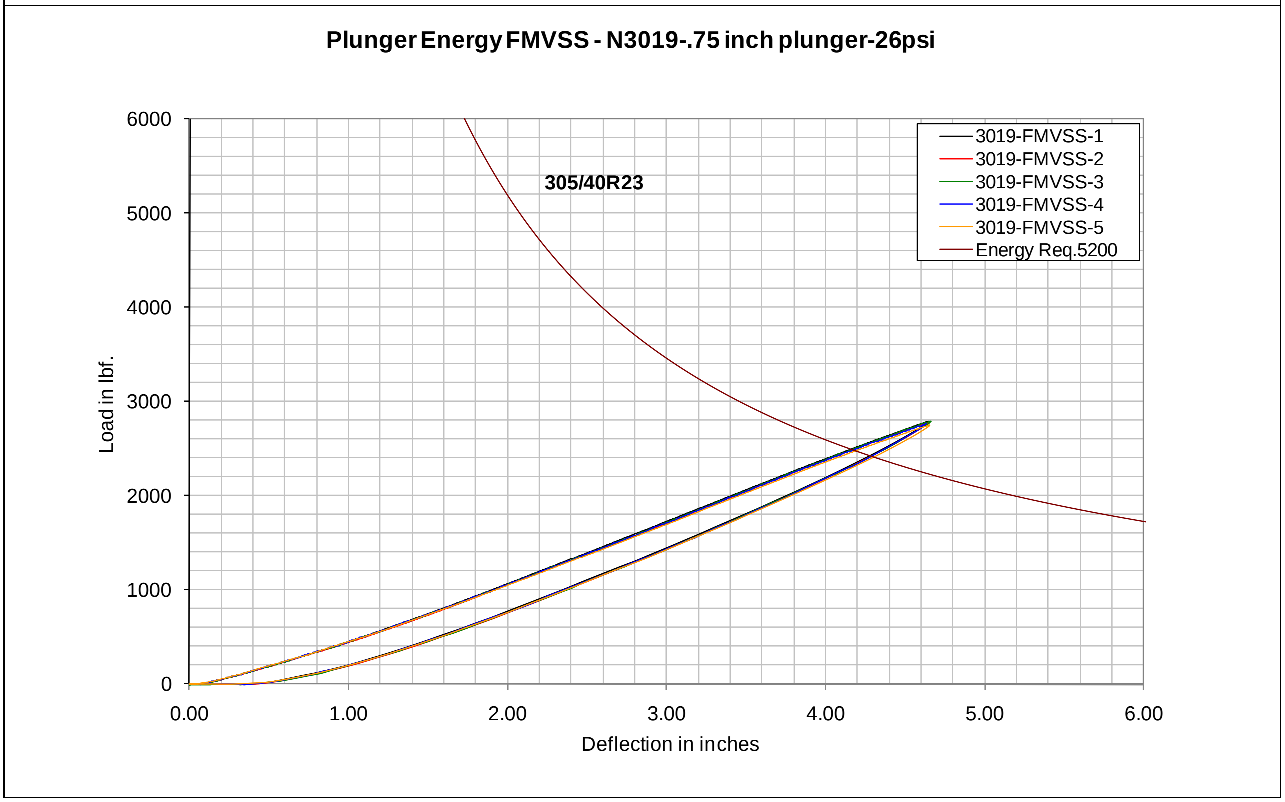


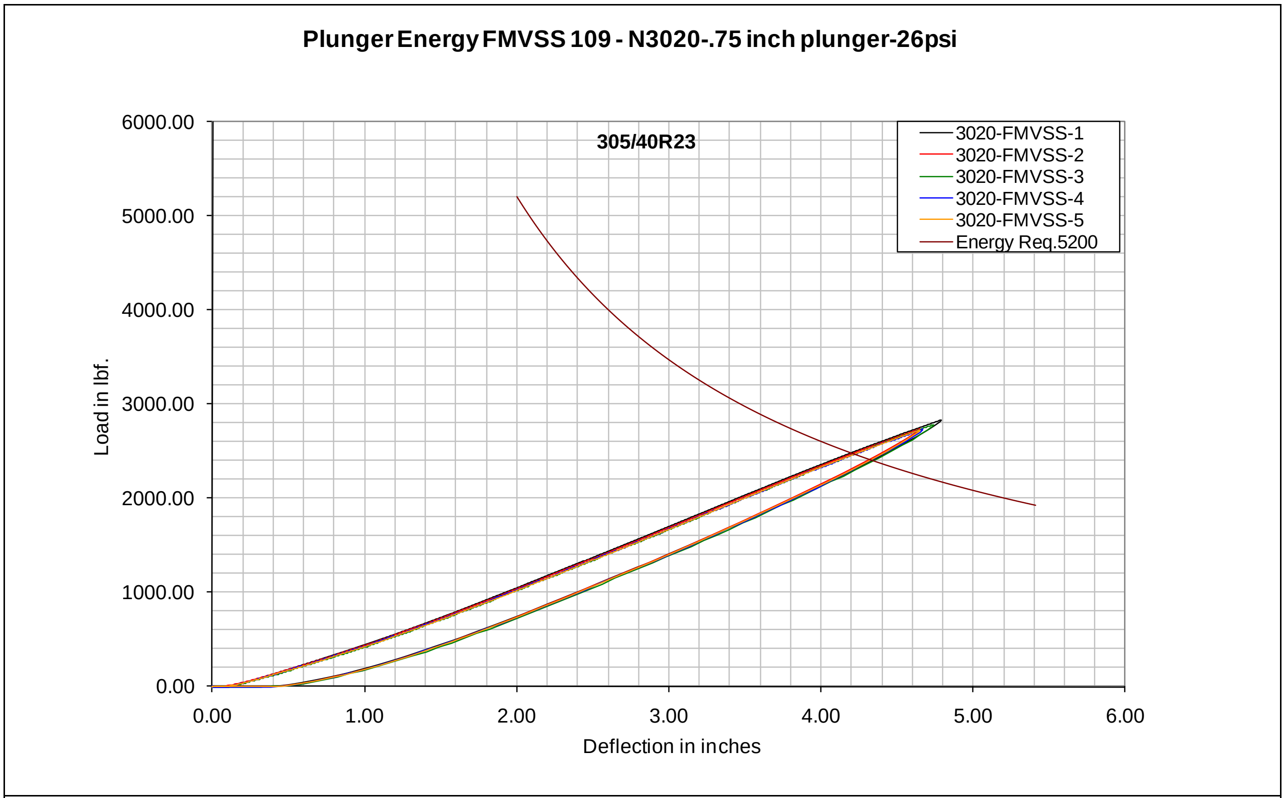


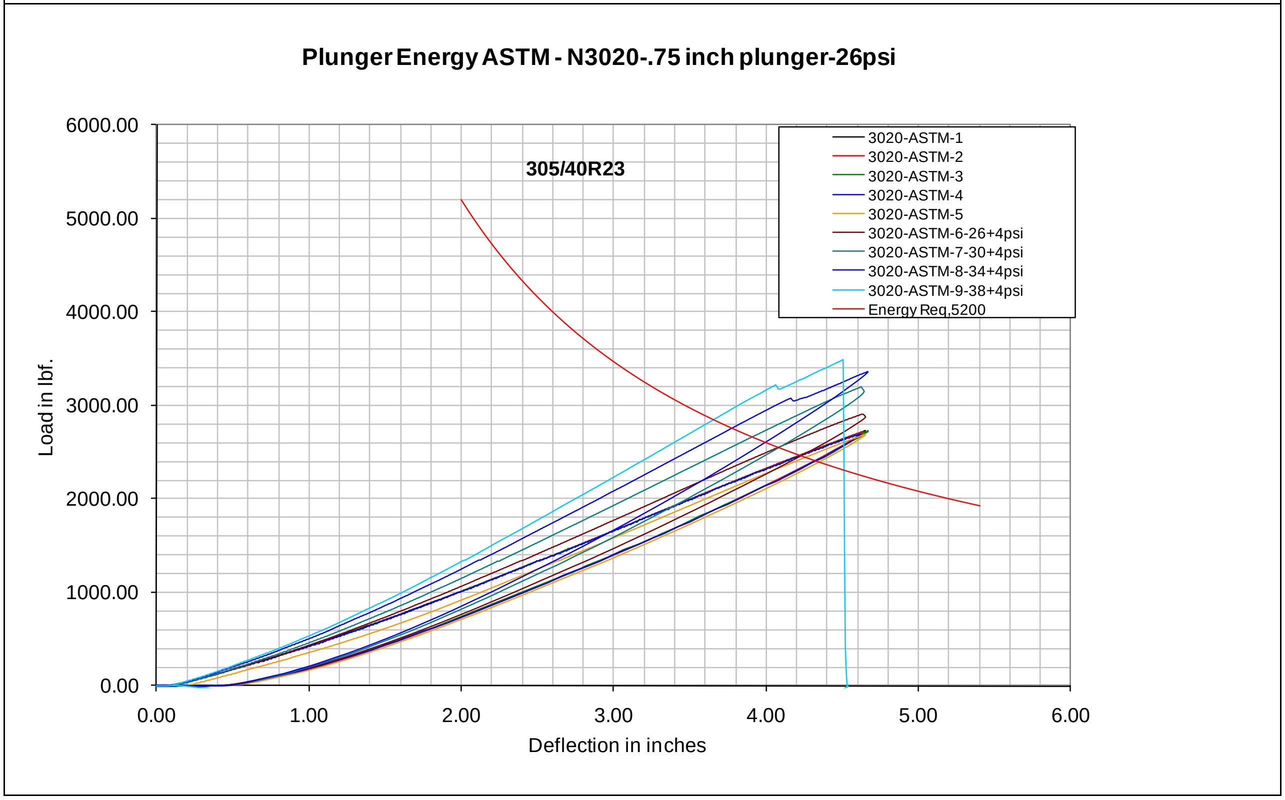

Plunger Energy ASTM - N3008-.75 inch plunger-
305/35R24
3008-ASTM-1
3008-ASTM-2
3008-ASTM-3
3008-ASTM-4
3008-ASTM-5
3008-ASTM-6-26+4PSI
3008-ASTM-7-30+4PSI
3008-ASTM-8-34+4PSI
Energy Req.5200
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

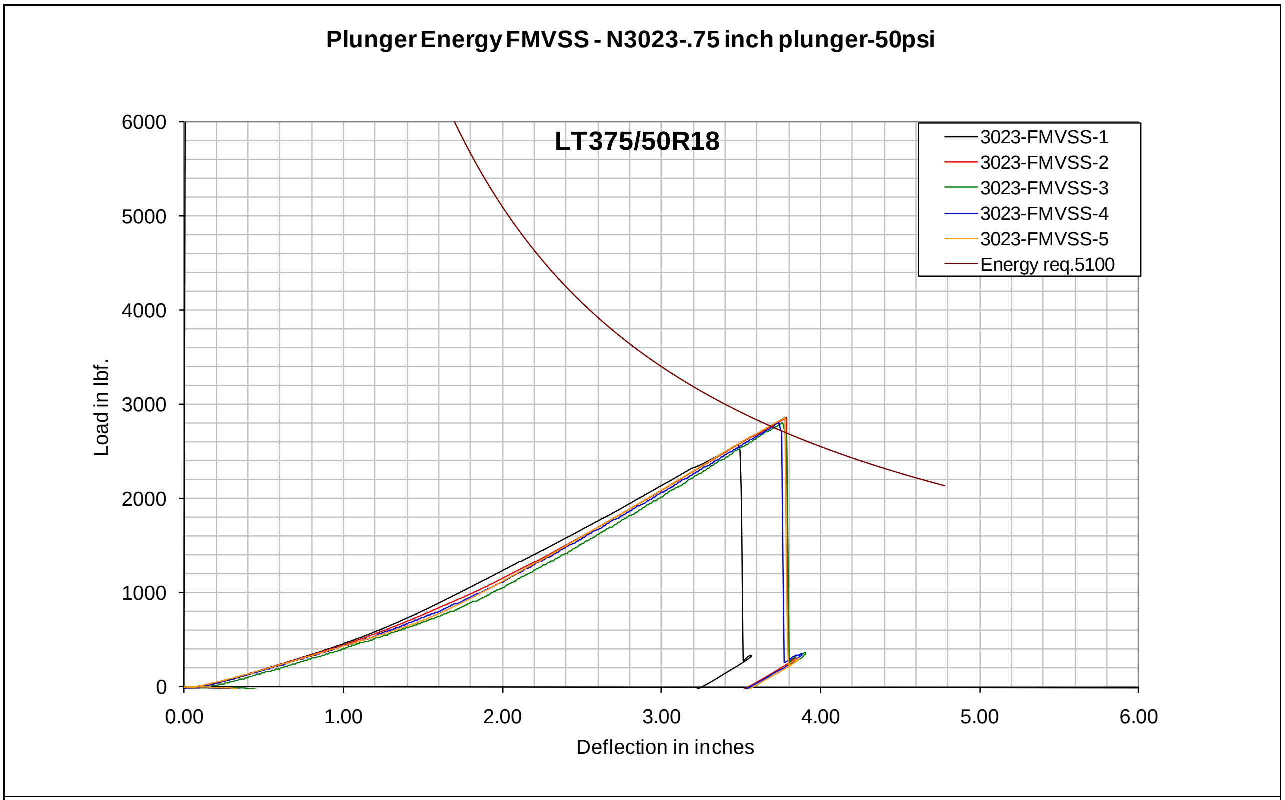

Plunger Energy FMVSS - N3028-.75 inch plunger-26psi
305/35R24
3028-FMVSS-1
3028-FMVSS-2
3028-FMVSS-3
3028-FMVSS-4
3028-FMVSS-5
Energy Req.5200
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

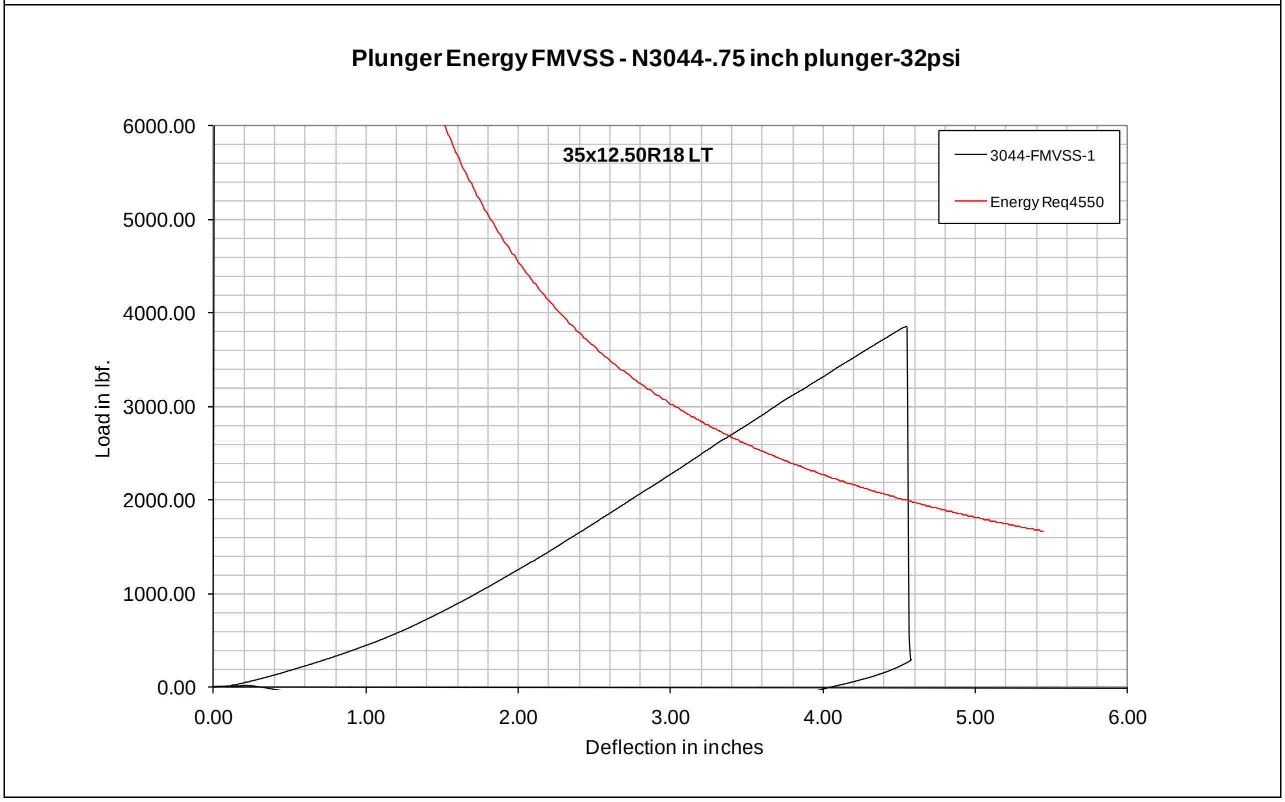

Plunger Energy ASTM - N3028-.75 inch plunger-26psi
305/35R24
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
Load in lbf.
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches
3028-ASTM-1
3028-ASTM-2
3028-ASTM-3
3028-ASTM-4
3028-ASTM-5
3028-ASTM-6-26+4PSI
3028-ASTM-7-30+4PSI
3028-ASTM-8-34+4PSI
3028-ASTM-9-38+4PSI
3028-ASTM-10-42+4PSI
Energy Req.5200

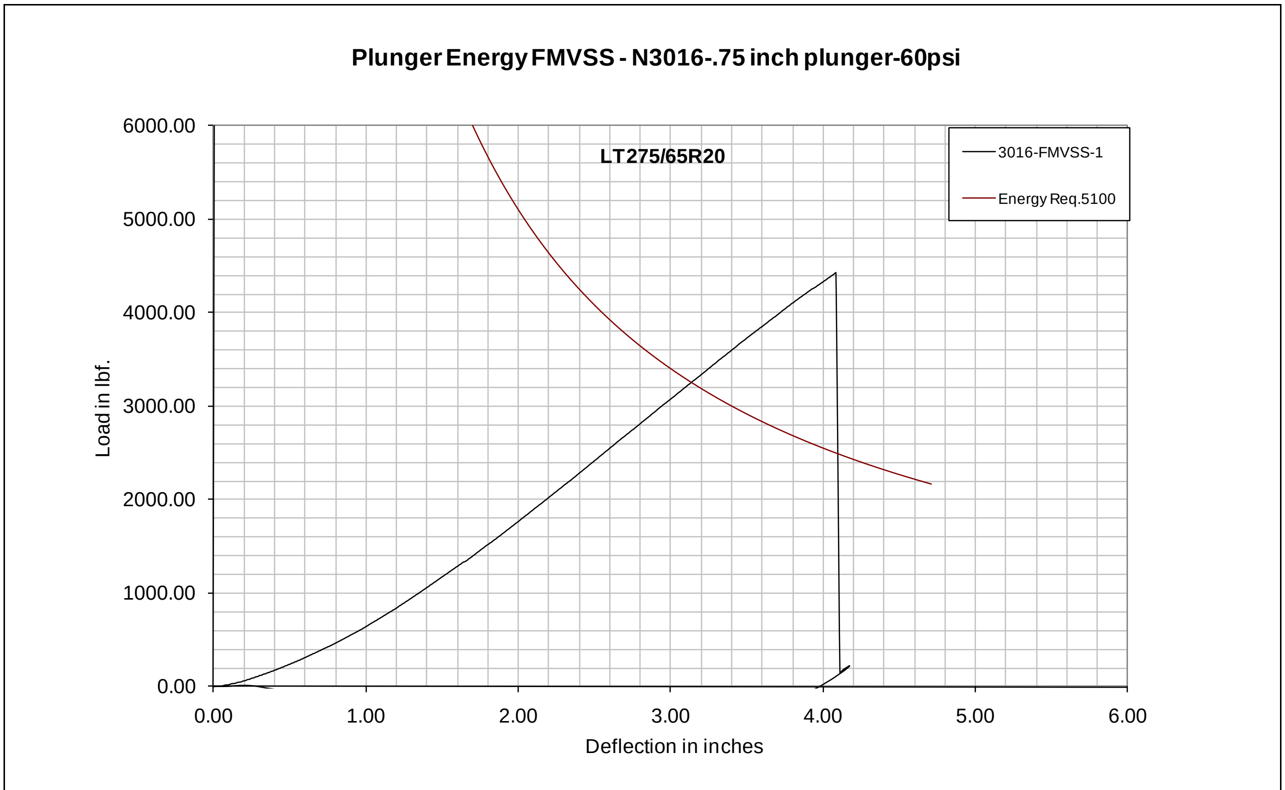

Plunger Energy FMVSS - N3019-.75 inch plunger-26psi
305/40R23
6000
5000
4000
3000
2000
1000
0
Load in lbf.
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches
3019-FMVSS-1
3019-FMVSS-2
3019-FMVSS-3
3019-FMVSS-4
3019-FMVSS-5
Energy Req.5200

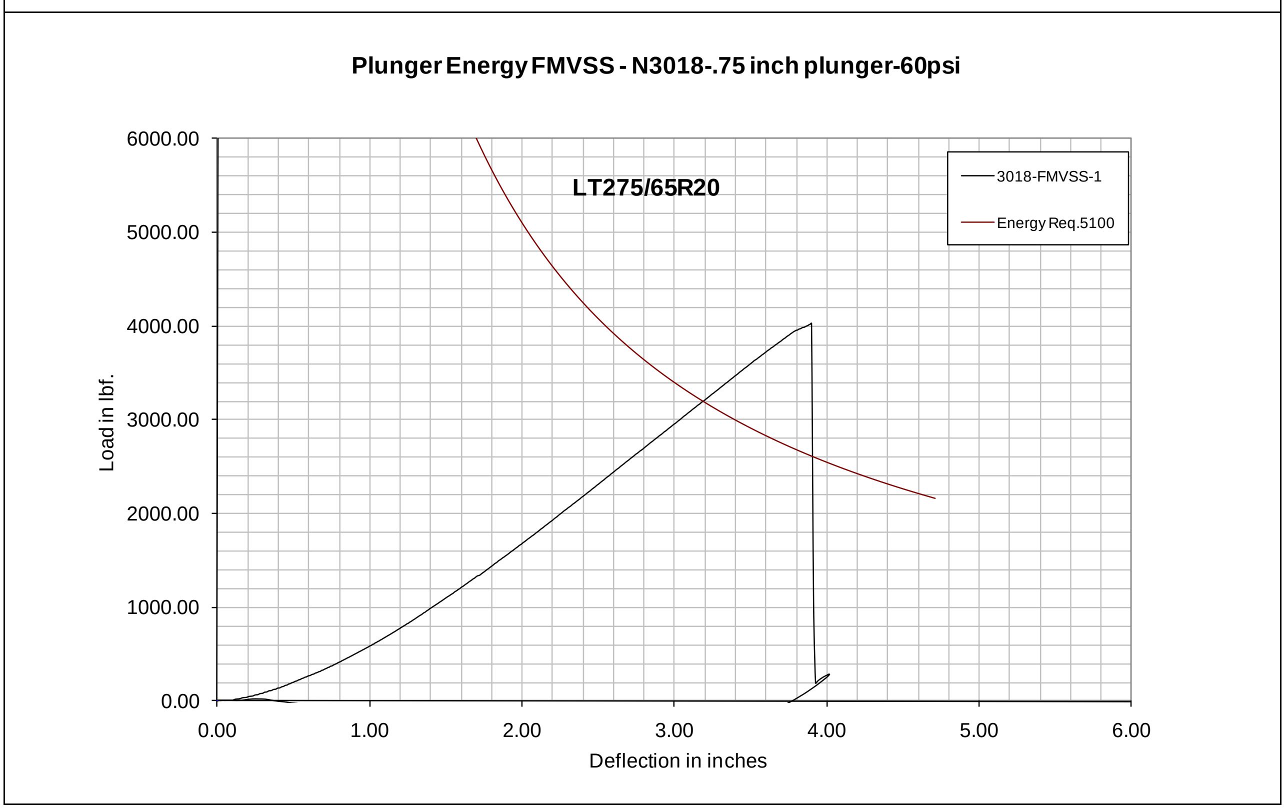

Plunger Energy FMVSS 109 - N3020-.75 inch plunger-26psi
305/40R23
3020-FMVSS-1
3020-FMVSS-2
3020-FMVSS-3
3020-FMVSS-4
3020-FMVSS-5
Energy Req.5200
Load in lbf.
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches


Plunger Energy ASTM - N3020-.75 inch plunger-26psi
305/40R23
3020-ASTM-1
3020-ASTM-2
3020-ASTM-3
3020-ASTM-4
3020-ASTM-5
3020-ASTM-6-26+4psi
3020-ASTM-7-30+4psi
3020-ASTM-8-34+4psi
3020-ASTM-9-38+4psi
Energy Req.5200
Load in lbf.
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches


Plunger Energy FMVSS - N3023-.75 inch plunger-50psi
LT375/50R18
3023-FMVSS-1
3023-FMVSS-2
3023-FMVSS-3
3023-FMVSS-4
3023-FMVSS-5
Energy req.5100
Load in lbf.
Deflection in inches
6000
5000
4000
3000
2000
1000
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00

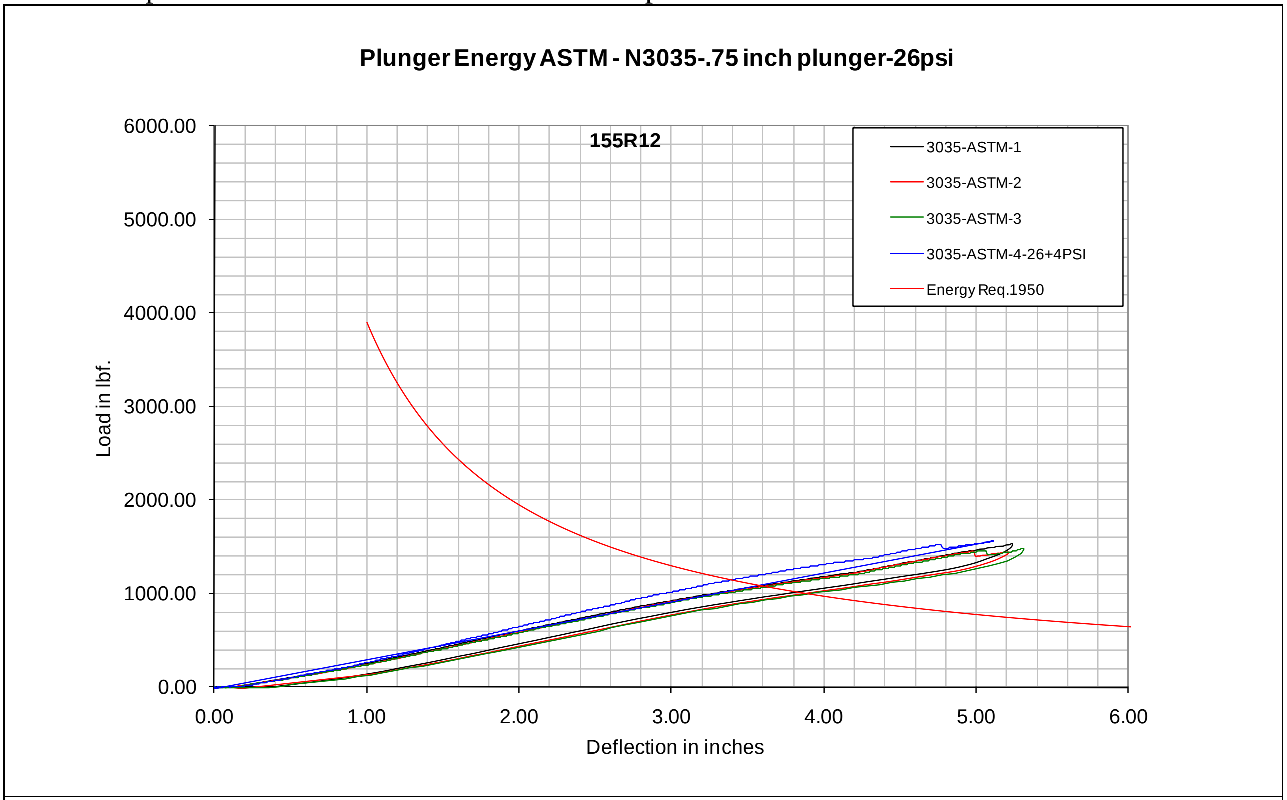

Plunger Energy FMVSS - N3044-.75 inch plunger-32psi
35x12.50R18 LT
3044-FMVSS-1
Energy Req4550
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

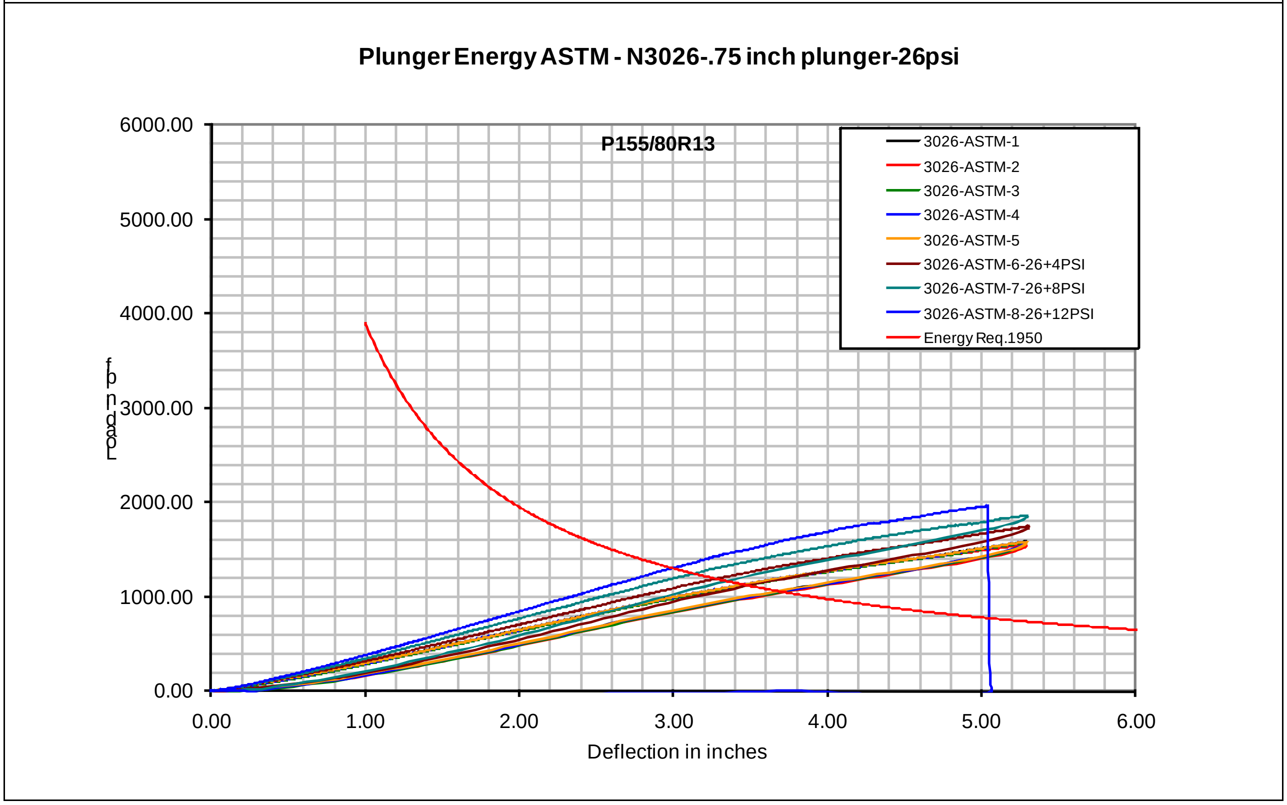

Plunger Energy FMVSS - N3016-.75 inch plunger-60psi
LT275/65R20
3016-FMVSS-1
Energy Req.5100
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

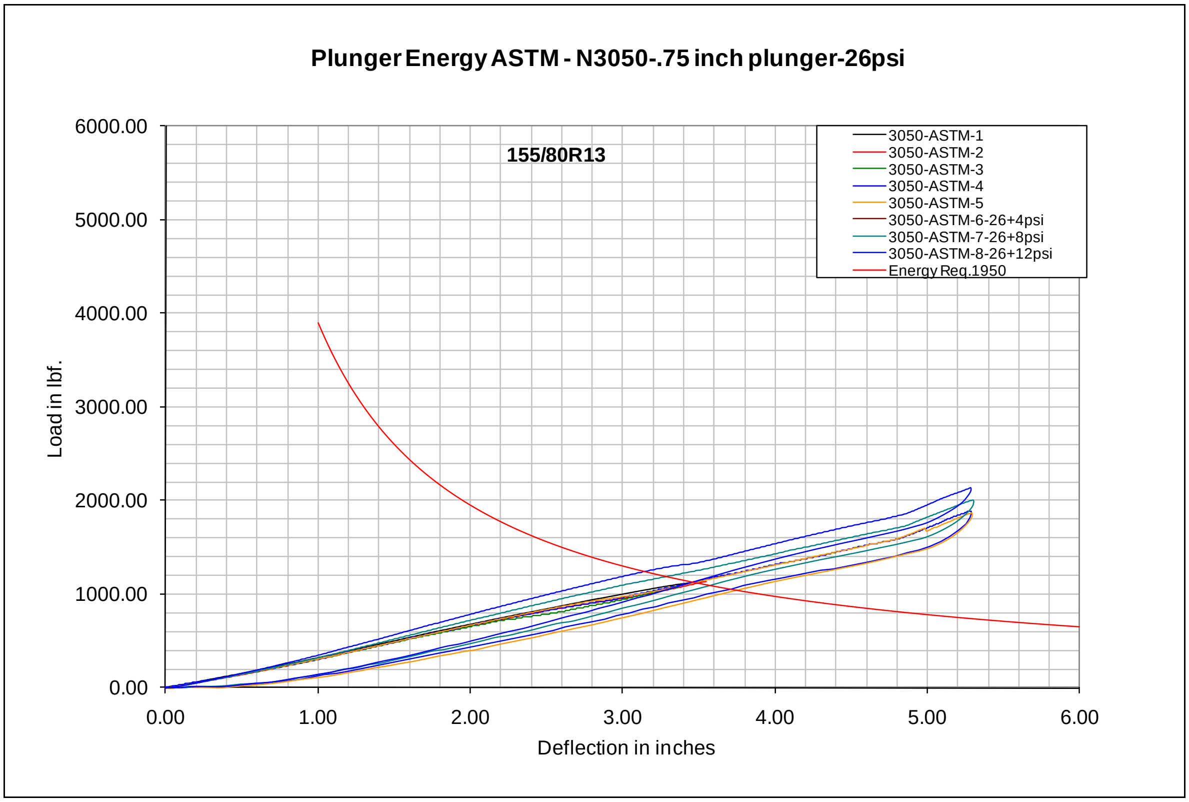

Plunger Energy FMVSS - N3018-.75 inch plunger-60psi
LT275/65R20
3018-FMVSS-1
Energy Req.5100
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

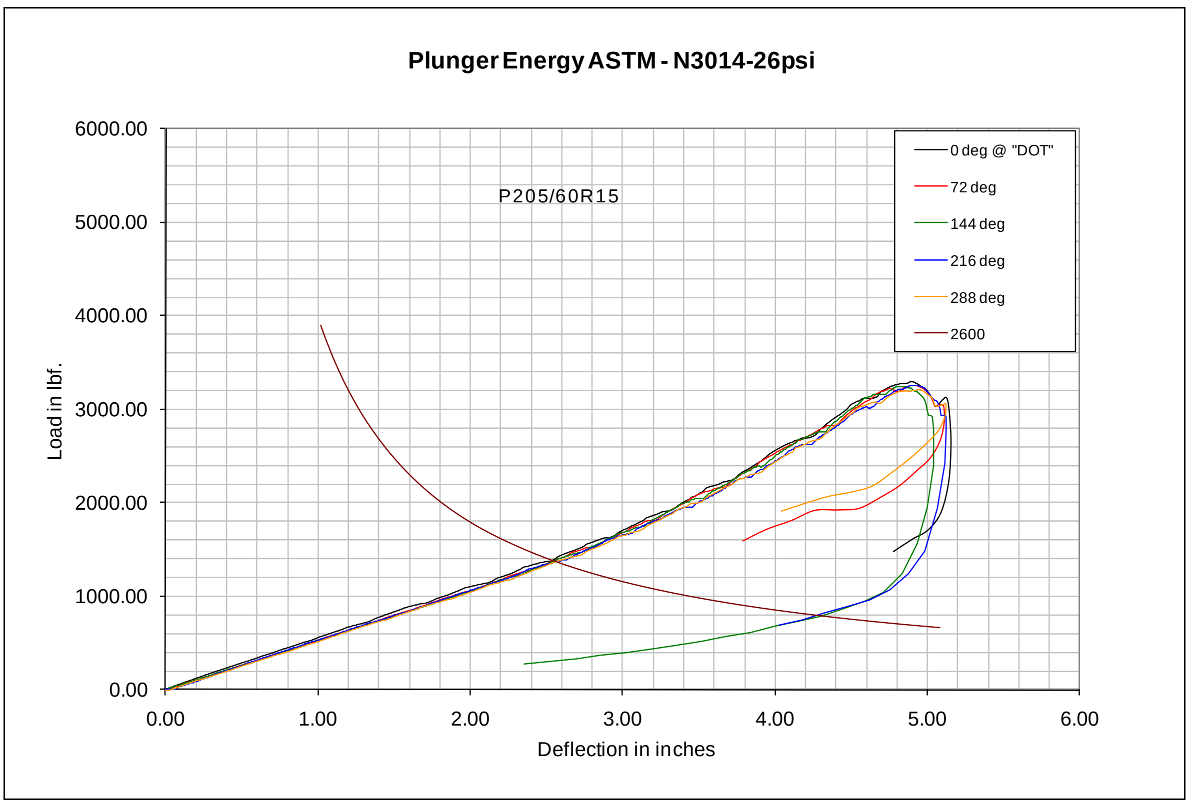
APPENDIX 3 ASTM F414-06 TESTS

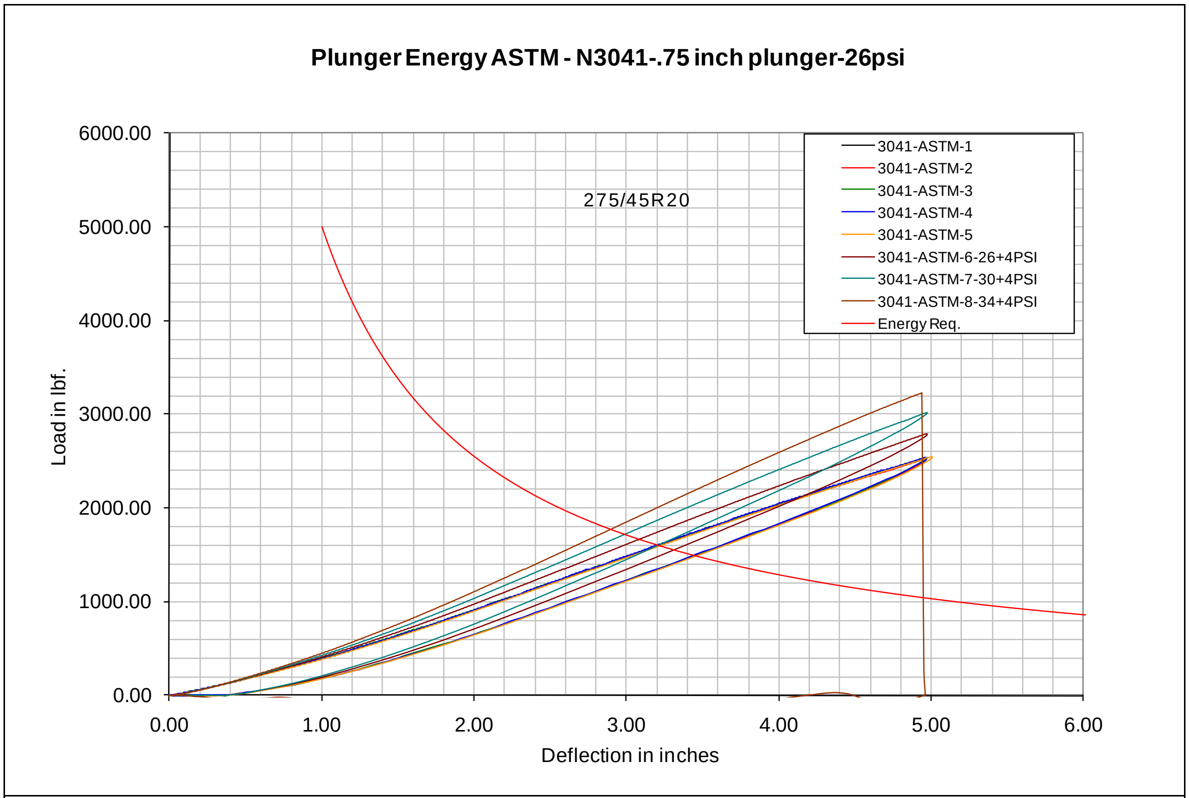
Note: Graphs of the ASTM F414-06 tests at low pressure are in Section 5.5.

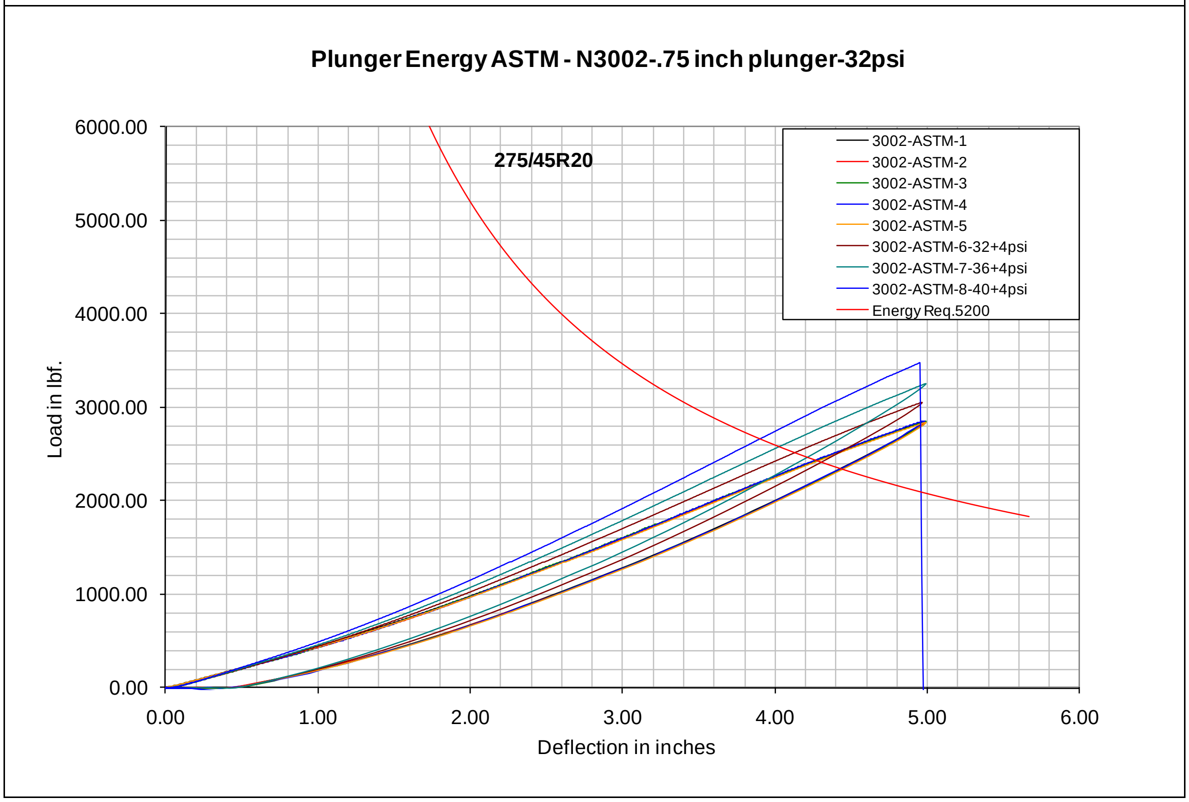




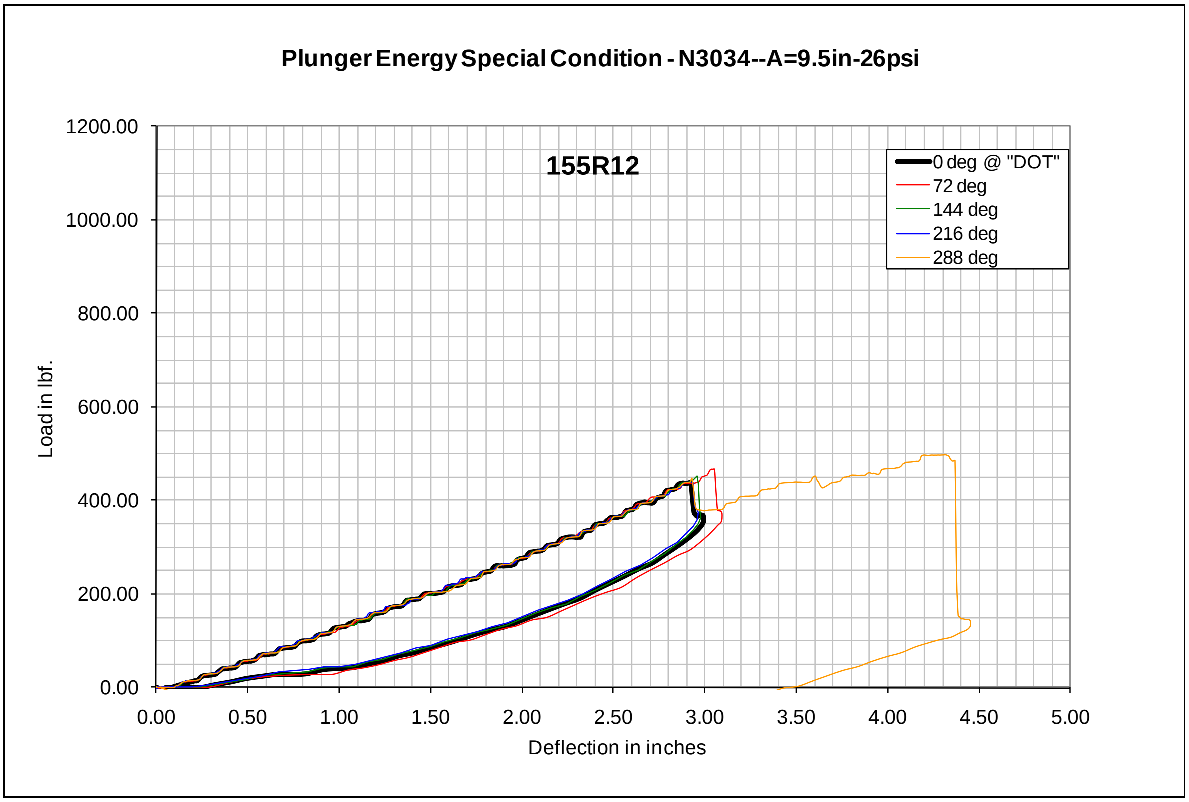

Plunger Energy ASTM - N3050-.75 inch plunger-26psi
155/80R13
3050-ASTM-1
3050-ASTM-2
3050-ASTM-3
3050-ASTM-4
3050-ASTM-5
3050-ASTM-6-26+4psi
3050-ASTM-7-26+8psi
3050-ASTM-8-26+12psi
Energy Req.1950
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

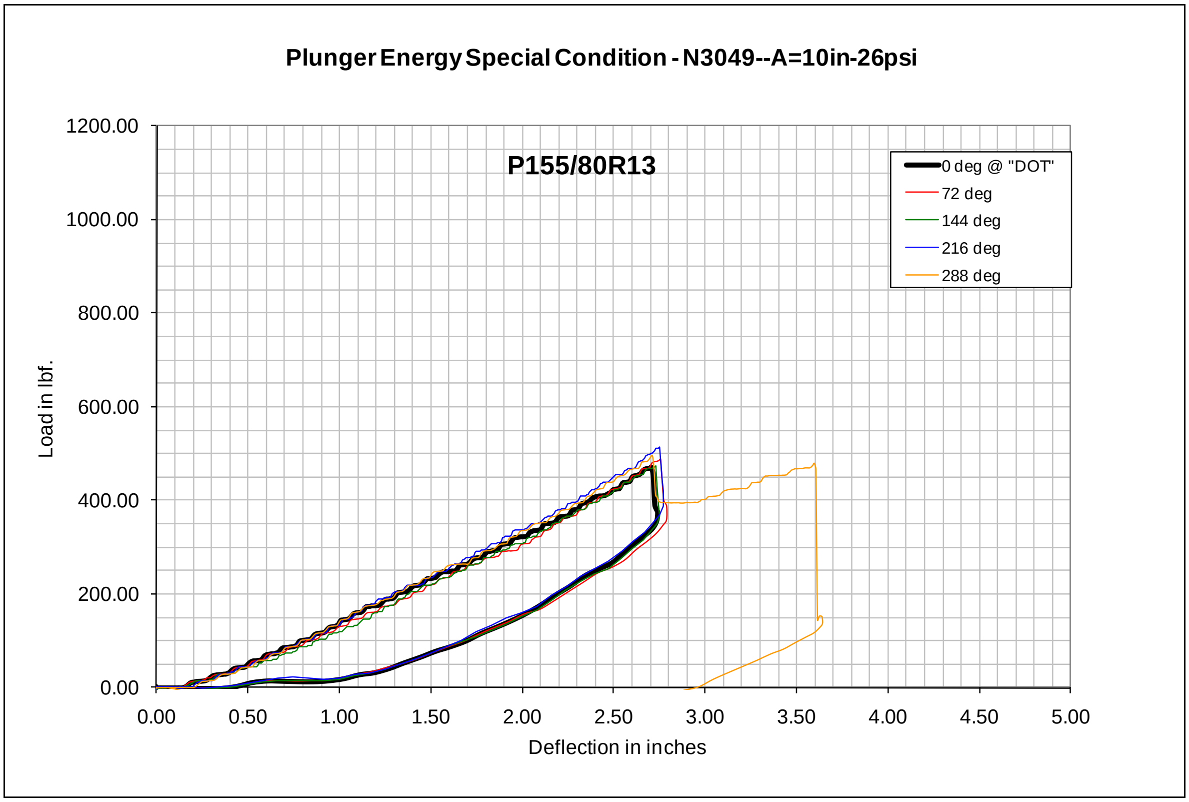

Plunger Energy ASTM - N3014-26psi
P205/60R15
0 deg @ "DOT"
72 deg
144 deg
216 deg
288 deg
2600
Load in lbf.
Deflection in inches
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00

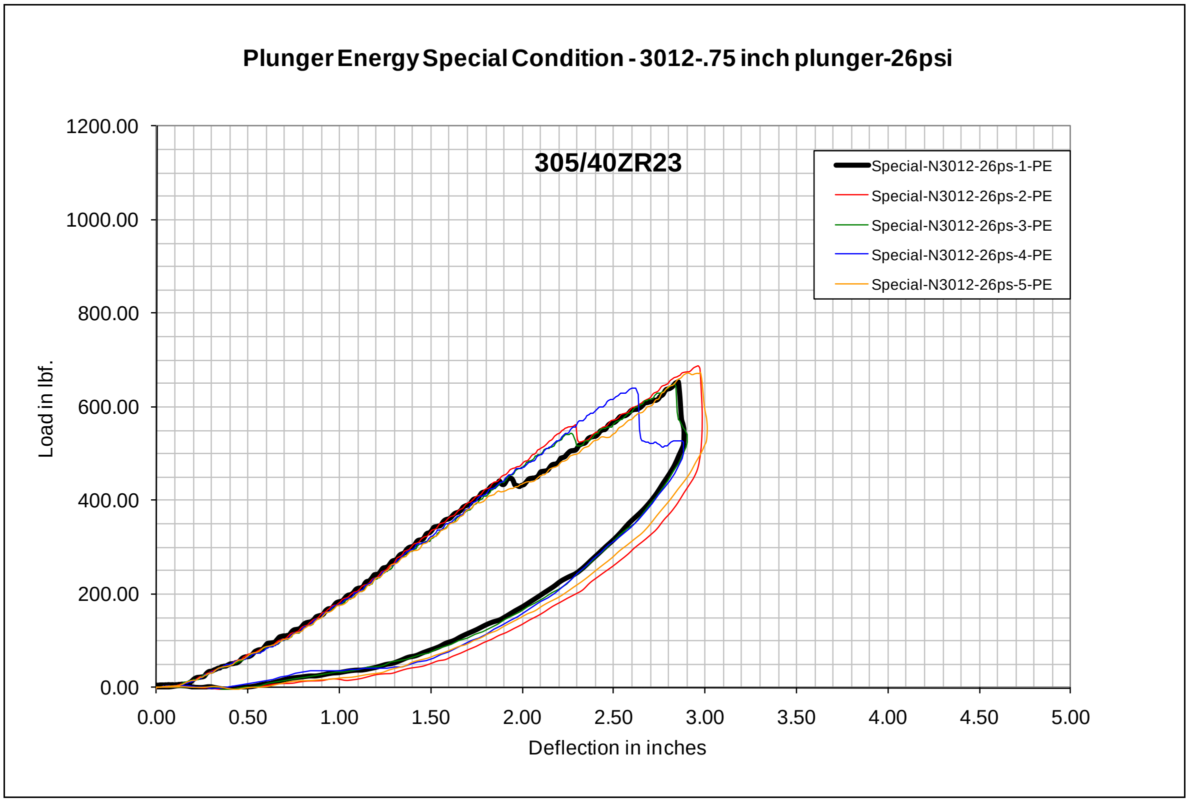

Plunger Energy ASTM - N3041-.75 inch plunger-26psi
275/45R20
3041-ASTM-1
3041-ASTM-2
3041-ASTM-3
3041-ASTM-4
3041-ASTM-5
3041-ASTM-6-26+4PSI
3041-ASTM-7-30+4PSI
3041-ASTM-8-34+4PSI
Energy Req.
Load in lbf.
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches

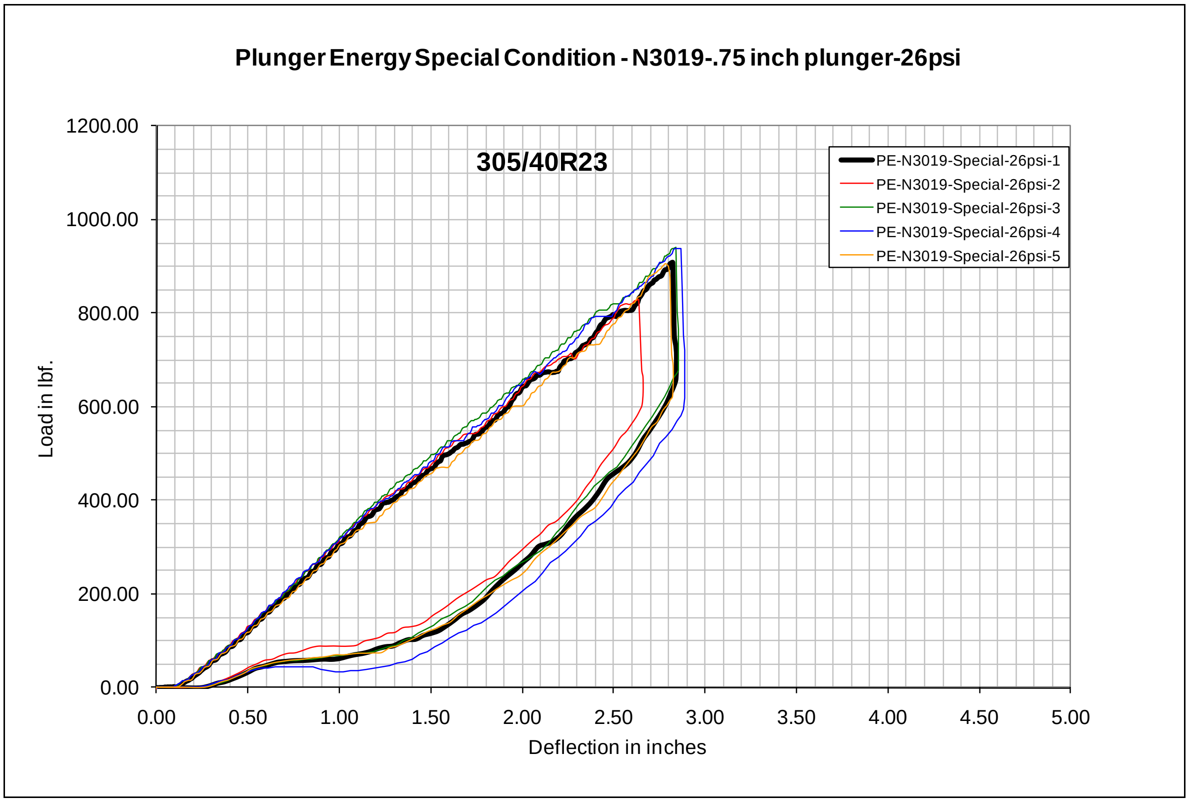

Plunger Energy ASTM - N3002-.75 inch plunger-32psi
275/45R20
3002-ASTM-1
3002-ASTM-2
3002-ASTM-3
3002-ASTM-4
3002-ASTM-5
3002-ASTM-6-32+4psi
3002-ASTM-7-36+4psi
3002-ASTM-8-40+4psi
Energy Req.5200
Load in lbf.
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Deflection in inches

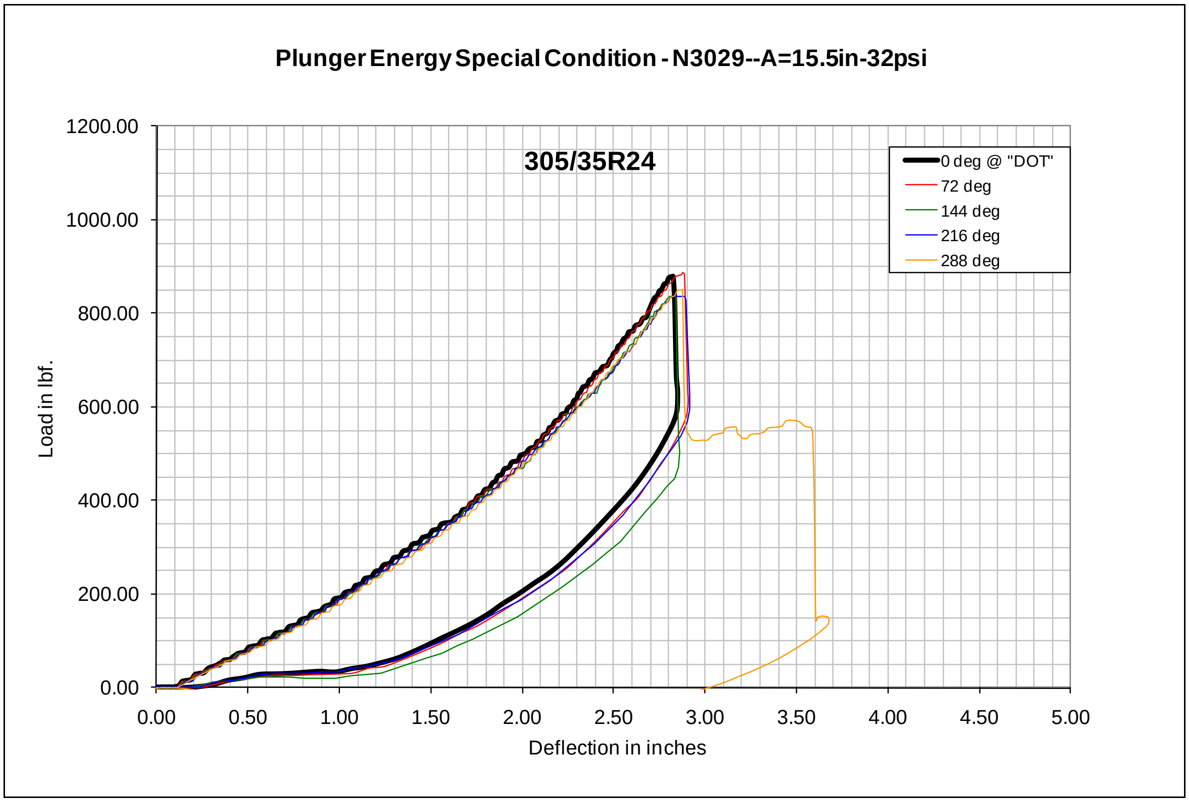
APPENDIX 4 SIDEWALL PLUNGER TESTS



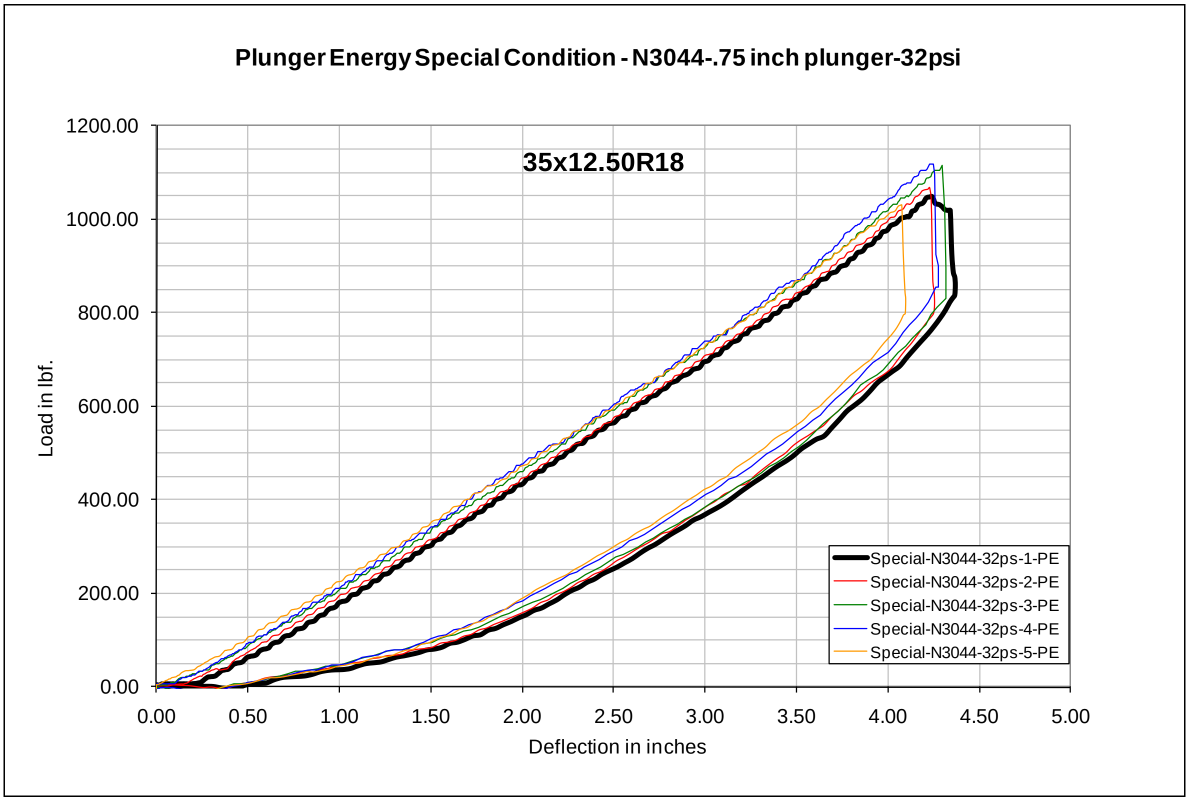



Plunger Energy Special Condition - 3012-.75 inch plunger-26psi
305/40ZR23
Special-N3012-26ps-1-PE
Special-N3012-26ps-2-PE
Special-N3012-26ps-3-PE
Special-N3012-26ps-4-PE
Special-N3012-26ps-5-PE
Load in lbf.
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Deflection in inches

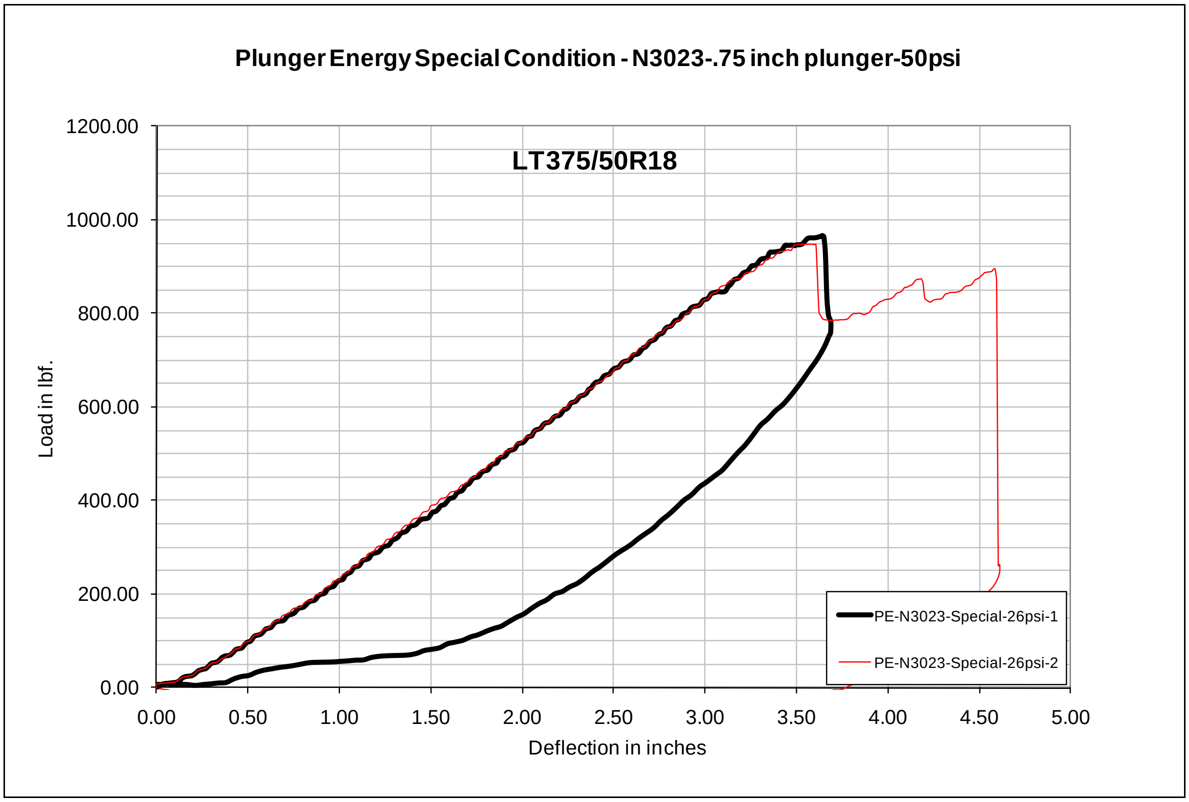

Plunger Energy Special Condition - N3019-.75 inch plunger-26psi
305/40R23
PE-N3019-Special-26psi-1
PE-N3019-Special-26psi-2
PE-N3019-Special-26psi-3
PE-N3019-Special-26psi-4
PE-N3019-Special-26psi-5
Load in lbf.
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Deflection in inches



Plunger Energy Special Condition - N3029--A=15.5in-32psi
305/35R24
0 deg @ "DOT"
72 deg
144 deg
216 deg
288 deg
Load in lbf.
Deflection in inches
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00



Plunger Energy Special Condition - N3044-.75 inch plunger-32psi
35x12.50R18
Special-N3044-32ps-1-PE
Special-N3044-32ps-2-PE
Special-N3044-32ps-3-PE
Special-N3044-32ps-4-PE
Special-N3044-32ps-5-PE
Load in lbf.
Deflection in inches
0.00
200.00
400.00
600.00
800.00
1000.00
1200.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00



Plunger Energy Special Condition - N3023-.75 inch plunger-50psi
LT375/50R18
Load in lbf.
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Deflection in inches
PE-N3023-Special-26psi-1
PE-N3023-Special-26psi-2

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