Automotive Seating Foam Hardness Review and Recommended Improved Testing Methodology

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ABSTRACT

Automotive cushion hardness is a critical property that has to be closely controlled by PUF manufacturers in order to ensure occupant positioning during driving and comfort maintenance. Since the inception of flexible foam seating, initially using rubber latex foam, through to the use of high resiliency (HR) polyurethane foam cushions, part hardnesses have been measured using several types of testing regimes. The most common hardness test calls for a part to be indented to a specified deflection, e.g. by 50% of its initial thickness, and the force after a specified dwell time is recorded. Many OEMs specify hardness at 25, 40, 50, and /or 65% deflection with the force(s) recorded in Newtons. This is commonly referred to as Indentation Force Deflection or IFD. Other hardness methodologies have been or are in use. For instance, IRGL (Indentation Residual Gauge Length) was used by Ford Motor Company until several years ago and recently Johnson Controls, Inc. introduced and specified CPF (Constant Penetration Force) hardness. IRGL calls for selected forces to be applied to a part and the residual thicknesses under the indenter are recorded in millimeters. In contrast, the CPF test specifies that the foam part be indented by selected distances, e.g. 20mm, and the force in Newtons recorded. Many other hardness tests are in use throughout the PU industry, from standardization organizations and even from individual companies.

An extensive review of foam hardness methodologies has shown more than fifty different tests. Some only differ marginally from each other but very different results may result. A working group from the Molded Foam Industry Panel (www.moldedfoam-IP.org) reviewed these tests and in 2006 presented our initial work on hardness testing. At that time, four laboratories contributed results for a number of foam grades using IFD, IRGL and CPF methodologies.

Our most recent investigations have been completed by six laboratories most of whom are ISO17025 accredited. Foam grades covering a very wide range of automotive part densities and hardnesses have been evaluated with four different test methodologies by each laboratory. The data has been subjected to thorough analyses to determine which of the selected hardness tests produced the least variation in results between and within laboratories. Since all of these tests essentially involve indenting the foam using a specified deflection, specified force or a known distance, there should be reasonably good correlation between the results. However, it must be borne in mind that minor differences, e.g. holding or not holding a force at a specified deflection, can result in quite different hardness values.

Foam part firmness will be shown to be a reasonably exact science if performed using state-of-the-art equipment, in a controlled laboratory environment and using well-trained operators.

INTRODUCTION

Hardness testing of flexible polyurethane foams has always had reproducibility and repeatability issues within the automotive seating industry and so the Molded Foam Industry Panel decided to try to develop and recommend an improved testing methodology. A planned 'gauge R&R' type study on four test methods was carried out on a wide sample set of flexible polyurethane foam test blocks. Even with what we thought were very complete instructions on running the tests, we had much wider than expected variations between the six test labs that participated. A number of retests were carried out to try to improve the results, but in most cases the test labs simply reproduced their initial results. We thus verified many of the industry issues that currently exist with flexible foam hardness testing. These results led us to investigate the many reasons for this variability. While our objective for an improved testing methodology was not brought to fruition, we achieved a more complete understanding of the selected test methods and the sources of test variation within various polyurethane flexible foam systems.

EXPERIMENTAL BACKGROUND & SETUP

Hardness Test Methods Selected

While there are many different test methods to determine hardness of polyurethane flexible foams, we selected the four methods described in detail below:

1. <u>Indentation Force Deflection, IFD-ASTM</u>
   - ASTM D3574-08, Test B1

   This test is a historical standard for the industry measuring the force at various deflections into a foam cushion. Typical test deflections run are 25, 40, 50, and 65%. The 25% deflection value often is used by the slabstock industry as the definition of foam hardness, but the higher deflections of 40 or 50% are more often used for automotive seating. For this study, we selected deflections of 25 and 50% with a 60-second dwell time

2. <u>Indentation Residual Gauge Length, IRGL & IRGL-IP Modified</u>
   - ASTM D3574-08, Test B2-IRGL: (Original test defined in SAE J815)

   The original test was used some time ago by the Ford Motor Company but was replaced by the IFD test at 50% deflection.

The purpose of this method was to identify the residual foam thickness remaining at a given load, which can be then correlated to the H-point seating performance [1]. The method specified forces of 110 and 220 N, typical of the soft foams used in seating at that time. For this study we used a modified version with test loads of 100, 200, 300, 400, 500 N to cover the harder grades of seating foams typically used today. This test also uses a 60-second dwell time at the load test point before recording the residual thickness of the test sample.

3. Constant Penetration Force, CPF
   - CPNM-MOS-WI-10-04-02-E

   This method is used by Johnston Controls, Inc. and is described fully in a Johnson Controls Work Instruction [2]. It is a simple and fast test that preflexes the sample two times by 75% deflection. Immediately following the pre-compression cycles the sample is indented by 75% deflection and the test points at indentations of 15, 20, and 25 mm are taken as well as the hysteresis loss (see Appendix Fig 13). The CPF value at 20 mm is defined as the CPF hardness of the sample. The ratio of the 25 mm value divided by the 15 mm value defines the 'Comfort Index'.

4. IFD-Industry Panel Modified, IFD-IP Mod

   The objective of this test was to shorten the overall test time compared with the standard IFD-ASTM test by running at a faster crosshead speed of 500 mm/min, using five 75% deflection preflexes in place of two, eliminating the recovery period between preflex and test, and using only a 30-second dwell at the test points.

Please refer to the summary test methods in Table 1, which lists all the basic setup parameters for each test. For all the tests a standard 203 mm diameter indenter foot was used. While there is some commonality in the parameters, there are also enough differences that directly impact the results obtained. Thus, the hardness results are co-relatable, but different. The hardness testing of flexible foams is very unlike the well-defined compressive strength of engineering materials and has to be a totally defined test.

Table 1
Basic Hardness Test Parameters

	Parameter	ASTM IFD ASTM D3574-B1	Industry Panel Modified IFD	IRGL ASTM D3574-B2	Industry Panel Modified IRGL	CPF-JCI CPN-MOS-WI-10-04-02-E
Preflex	Preflex point	75%	75%	330 N	75%	75%
	Number of preflexes	2	5	2	2	2
	Preflex speed	250 mm/min.	500 mm/min.	200 mm/min.	200 mm/min.	300 mm/min.
	Zero force after preflex	Yes	Yes	Yes	Yes	Yes
Reference Height	Height reference after preflex	Yes	Yes	Yes	Yes	Yes
	Height reference preload	4.5 N	10 N	4.5 N	4.5 N	4.5 N
	Approach speed to ref. height	50 mm/min.	50 mm/min.	50 mm/min.	50 mm/min.	50 mm/min.
Test Points	Dwell after reference height	5 min.	0 min.	5 min.	5 min.	0 min.
	Test points	25 & 50%	25 & 50%	4.5, 110 & 220 N	4.5, 100, 200, 300, 400, 500 N	15, 20, 25 mm
	Test speed	50 mm/min.	500 mm/min.	50 mm/min.	50 mm/min.	300 mm/min.
	Dwell at test points	60 sec.	30 sec.	60 sec.	60 sec.	0 sec.

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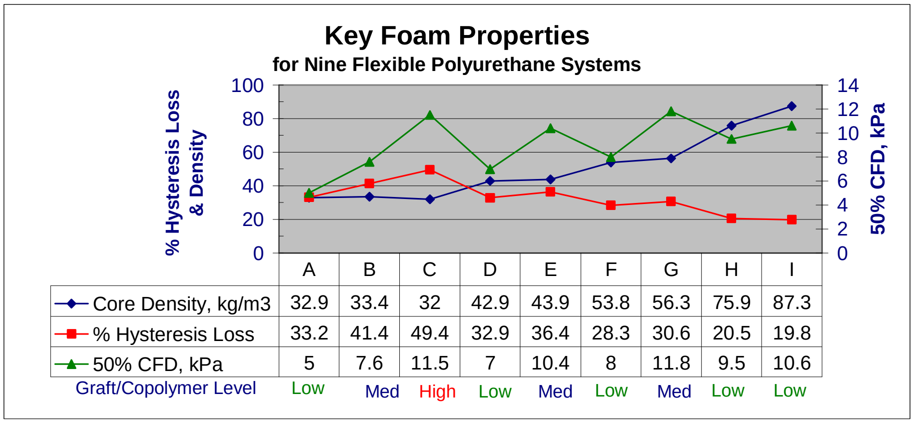


	A	B	C	D	E	F	G	H	I
Core Density, kg/m3	32.9	33.4	32	42.9	43.9	53.8	56.3	75.9	87.3
% Hysteresis Loss	33.2	41.4	49.4	32.9	36.4	28.3	30.6	20.5	19.8
50% CFD, kPa	5	7.6	11.5	7	10.4	8	11.8	9.5	10.6
Graft/Copolymer Level	Low	Med	High	Low	Med	Low	Med	Low	Low

Figure 1.

Flexible Foam Samples Tested

We purposely selected a wide range of TDI-based flexible molded polyurethane foams with densities of about 32 – 85 kg/m3 with different loadings of graft/copolymer polyol to adjust hardness at the different densities. The nine flexible foam samples tested were molded rectilinear blocks with dimensions of 380 x 380 x 50 mm. A 50 mm thickness was selected, as it is representative of most automotive seats designed today.

Please note that this study only deals with the hardness test variability of a simple molded foam test block. An actual automotive seat would have a more complex geometrical shape and many additional encapsulated elements such as wires, hook fasteners and backing material, which would greatly increase the test error.

The core densities and compression force deflection (CFD) data were obtained from cut samples on a duplicate set of molded blocks as described in ASTM D 3574-08 [3]. The base foam properties and descriptions of the nine samples (A-I) are shown in Figure 1. The hysteresis loss (HL) values shown here were actually the average results from the CPF test for the six labs that participated. This hysteresis loss (see Appendix Fig 13) results do not include the 6 $\pm$ 1 minute waiting period described in ASTM D 3574 Appendix X6.2 for IFD Hysteresis Loss.

Participating Test Labs

Six test labs participated including two chemical suppliers, two Tier 1s and two foam molders. Several different versions of equipment and software were used, five of which were completely automated and one was semi-automated. In all cases, the test operators were very skilled with many years of experience. However, in some cases the test operators had little or no experience running some of these tests, e.g. IFD-IP Modified and CPF. The standard IFD-ASTM test was probably the most familiar test to all the labs.

Methodology

All foams had achieved a fully cured state and were conditioned for at least 12 hours at 23 +/- 2 C at 50% +/- 5% relative humidity before start of testing for each of the labs. Additionally, the foams were allowed to recover for a minimum of 24 hours between tests to allow for recovery of hardness due to hysteresis loss during testing.

HARDNESS STUDY OBJECTIVES

Initially, we assessed the data results as a percent difference from the six lab average and calculated the standard deviations of the results for the six labs. Our hope was to have no more than a 2% difference as being fully acceptable for a gauge R&R. However, we had labs with differences of more than 5% and even up to about 20%. Based on these differences it became meaningless to pursue a strictly statistical R&R with such variation. The objective was changed to understanding the basis of these variations and we engaged in various retests and revisions. In some cases, we obtained significant improvements but in other cases, the test labs simply verified their prior results. This indicated that the lab was running a consistent methodology or program, yet was somewhat different from the other labs. Unfortunately, we did not have the time to investigate or identify all the sources of these differences.

In lieu of removing the gauge R&R portion, but still in keeping with developing an improved test methodology we decided to focus on two objectives for this hardness testing study:

1) Understanding the sources of variation affecting repeatability and reproducibility.
2) Understanding hardness results for the different methods and the potential of a method to improve seat design.

We theorized that the variability could come from at least three sources:

1.1) From the method itself and the programming capability to carry out preflex conditioning, set point reference height and test point measurements all at exact points in time for a series and also between all the test labs.

1.2) From the material itself and the well known visco-elastic response of polyurethane materials to property measurements [5].

1.3) Interaction of the method with the material response would be a third source of the observed variability.

RESULTS AND DISCUSSION

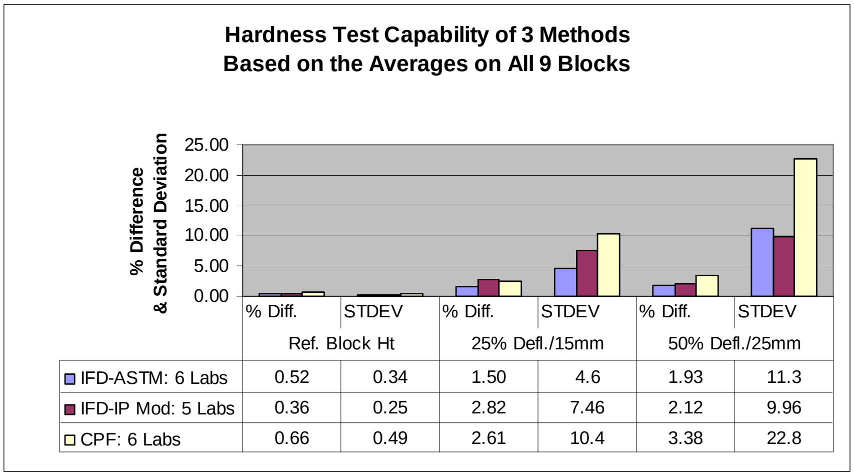
Tabulated Results

The final summaries of R&R test results for the labs participating are listed in the Appendix in Tables 3 – 7. We actually had retests of some of the methods by four of the labs, but it is not possible to include all this data. While the intention was to obtain results from all six labs, some labs had to be dropped due to their high variances. Please note that any labs that were dropped from the evaluation exhibit 'strike-through' data (line through the data) and are thus eliminated from the averages. The percent difference results were averaged as positive absolute values even if they were sometimes negative, so as not to cancel out the differences. The IRGL results in Table 6 and 7 are the raw data for the penetrations in mm into the foam at the given loads. To convert this data to IRGL or the height retained by the foam for each load it is necessary to subtract the raw penetration values from the reference block height values.

Overall Test Capability

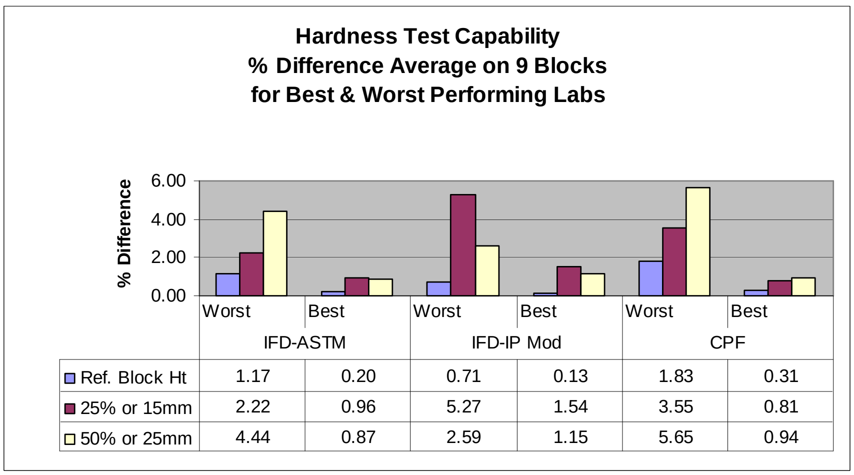
We used the percent difference from the average of the participating labs as the primary basis for determining test method variability. Secondly, we calculated the average standard deviation of the whole series of nine test samples for a given test lab as another criterion. Based on acceptability of the data, six labs were included for the IFD-ASTM and the CPF tests, while five labs were included for the IFD-IP Modified test. We had to drop the lab having the least programming capability as it led to as much as an 18% positive difference from the remaining five labs. In the case of the IRGL-IP Modified test and due to time constraints, only three labs were included out of four, as one lab was a definite outlier.

Initially, we compared the IFD-ASTM, IFD-IP Modified, and CPF tests as they all test the force at a given deflection whether by percent or mm of penetration. The IRGL-IP Modified method will be treated separately later. Figure 2 clearly shows that the IFD-ASTM method is the most capable as percent differences were kept below 2% on average for all the samples tested and standard deviations were also low. We attribute the good results on the IFD-ASTM test to the lab personnel's familiarity of this test and procedure. It is very apparent that the CPF method gives higher standard deviations than the other two methods. Figure 3 gives a better indication of the range of the testing variability by showing the average lowest and highest percent differences for each method for the five or six labs. This shows that some of the labs were capable of about a 1% difference, which is an excellent result. On the other hand, the worst result for many of the labs was about 5%. This means that we should not judge the test methods solely based on statistical variability, as there is the potential for low variability, if we can duplicate all the test conditions or programming of the good labs. By dropping the outlier labs and including those within about a 1 to 2% difference, typically we reduced the average standard deviations by about one-half.



	Ref. Block Ht		25% Defl./15mm		50% Defl./25mm	
	% Diff.	STDEV	% Diff.	STDEV	% Diff.	STDEV
IFD-ASTM: 6 Labs	0.52	0.34	1.50	4.6	1.93	11.3
IFD-IP Mod: 5 Labs	0.36	0.25	2.82	7.46	2.12	9.96
CPF: 6 Labs	0.66	0.49	2.61	10.4	3.38	22.8

Figure 2.



	IFD-ASTM		IFD-IP Mod		CPF	
	Worst	Best	Worst	Best	Worst	Best
Ref. Block Ht	1.17	0.20	0.71	0.13	1.83	0.31
25% or 15mm	2.22	0.96	5.27	1.54	3.55	0.81
50% or 25mm	4.44	0.87	2.59	1.15	5.65	0.94

Figure 3.

Material/System Variability

In the next phase of our evaluation, we wanted to determine the variability due to the foam samples themselves, as we knew we had selected a wide range of foam chemistries. An initial scan of the individual sample results showed that some samples had quite low percent difference and standard deviation, while others tended to have more variation. It was apparent that the sample behavior itself was also a major factor in the variability and this phenomenon was consistent to all four test methods. For this analysis, we sorted the samples in order of the softest to hardest foams based on the IFD-ASTM 50% deflection value, since this value is typically used in automotive seating. Figure 4 is a plot of the average percent difference and Figure 5 is a plot of the standard deviations for each of the nine samples tested. Both figures only show the results at 50% deflection or 20 mm penetration for the CPF method. Note that we have also plotted in these figures the percent hysteresis loss of the samples in order to assess how the visco-elastic response of the individual samples might influence the variability.

For a brief explanation of percent hysteresis loss, please see Figure 13 in the Appendix. Hysteresis can simply be described as the ability of a flexible polyurethane foam to return to its original support characteristics after it is compressed. This height or hardness load loss is recoverable, but requires some time period to return to its original state.

Our first observation was that sample C had a higher response than all the other samples. Sample C is high in hardness and has the highest percent hysteresis loss of all the samples tested. The second observation was the very high correlation between the percent hysteresis loss data and almost all of the other plotted data. Note that the line graphs for percent difference for the IFD-IP Modified and the CPF tests are almost mirror images of the percent hysteresis data and similar very strong trends hold for the standard deviations data. This initial data analysis strongly supported the hypothesis that the visco-elastic response of the samples would be a strong contributor to variability. It is important to note that the IFD-ASTM test results are not as strongly correlated with the hysteresis loss of the samples. This is believed to be due to the long rest period of 5 minutes between preflex and testing and the fact that the test values are measured after a 60-second dwell at the deflection points. Thus, the IFD-ASTM test masks the influence of hysteresis loss in the measurement by allowing hardness recovery after preflexing. The 60-second dwell before the hardness measurement is recorded, simulates a person settling into a foam cushion, thus also diminishing the influence of hysteresis loss. It appears that the original designers of the IFD-ASTM test purposely tried to minimize variability caused by hysteresis loss.

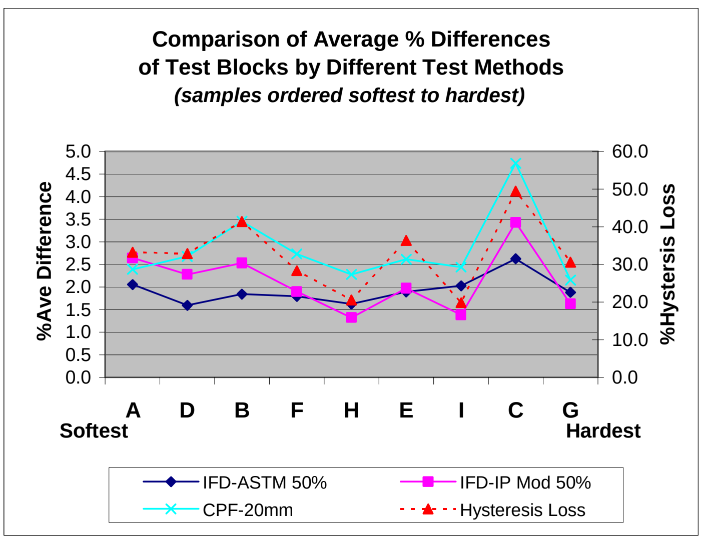


Figure 4.

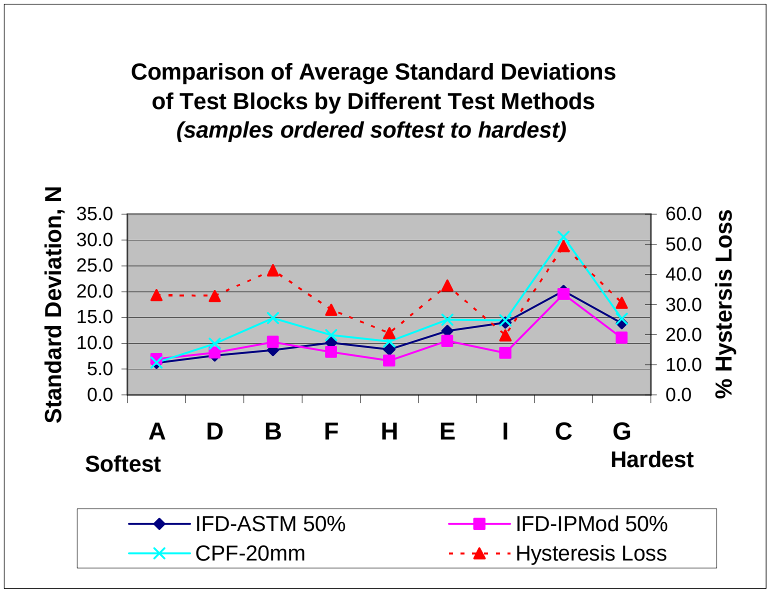


Figure 5.

Material and Method Interactions

Reference Heights

The initial variability analysis Figure 2 indicated that measurement of the reference block heights to establish a consistent starting point for hardness determination of the samples was not a contributing factor. This result is further verified by actual reference point heights measured for each of the test samples. In this case, the IRGL-IP Modified test results were also included in the analysis. See Figure 6 The actual block heights measured for each of the four test methods only varied over an approximately 0.25mm range and reproduced the same pattern for each of the samples. Even a force difference of 10 N for the IFD-IP Modified versus 4.5 N for the other three tests made no significant difference. Once again there is a very strong correlation of this pattern to the actual hysteresis loss reported for each of the samples except for sample A the softest sample.

Comparison of Hardness Methods

We wanted to understand clearly any differences between methods for the samples tested. In order to achieve this comparison, delta hardness differences between the various test methods were plotted. The results in Figure 7 show the differences between the IFD-IP Modified and IFD-ASTM tests. It is interesting that the delta hardness differences are almost exactly the same between the two deflections. As expected, the IFD-IP Modified test gives much lower hardness results due to the hysteresis loss having greater influence on that test. It is certain that, the five preflexes by 75% deflection without any recovery time period before measuring the hardness is the primary contributor along with the 30-second delay at the deflection test point. When we plotted the hysteresis loss values to check for any interaction, the almost mirror image correlation was very surprising.

The delta hardness differences between the CPF-JCI and IFD-ASTM test in Figure 8 are even more dramatic than those in Figure 7. Once again, there is a very strong correlation between the sample hysteresis loss and the hardness differences. The CPF-25mm (50% deflection on a 50 mm cushion) hardness results are 50 to 100 N higher than the IFD-ASTM test. The results in Figures 7 and 8 definitely illustrate the dependence of the hardness measurement on a particular foam sample and how the test method impacts the hardness value.

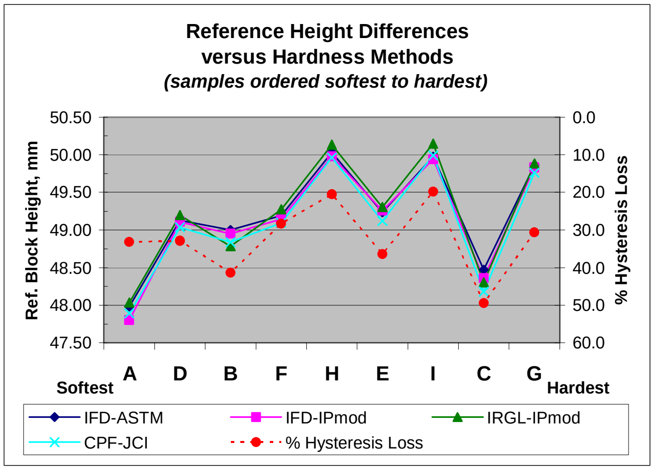


Figure 6.

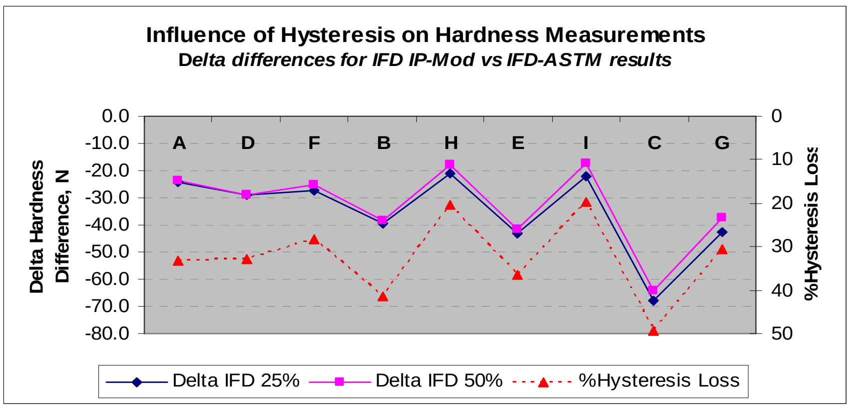


Figure 7.

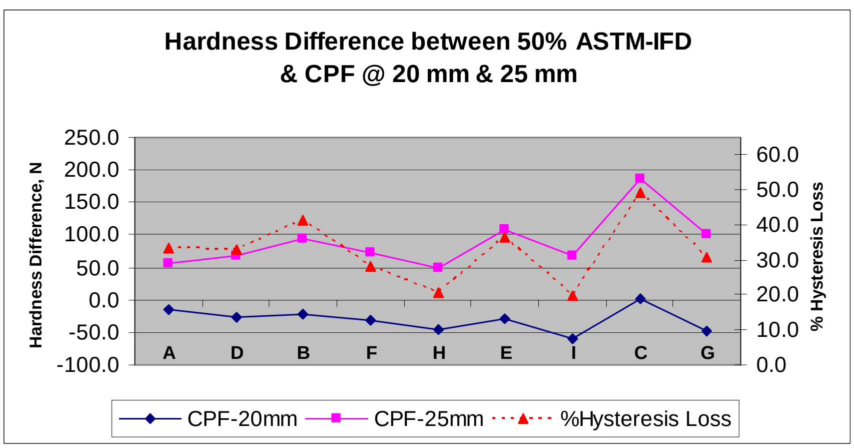


Figure 8.

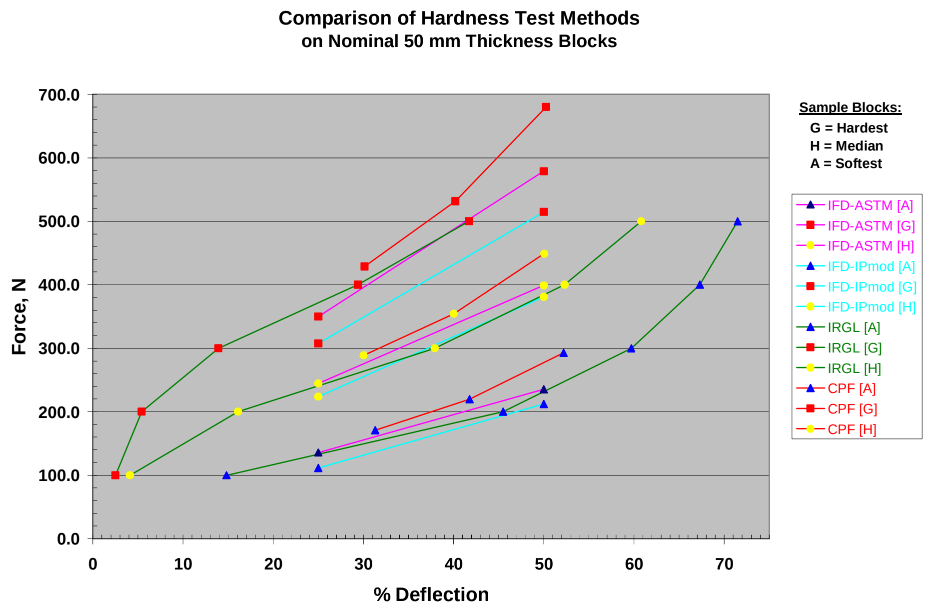


Figure 9.

Standard Force versus Deflection Curves

Our analyses, especially in Figures 7 and 8 clearly illustrates the importance that the visco-elastic response of polyurethane flexible foam has on the hardness results in combination with the method used. Thus, it is extremely important to understand the different hardness results that are achieved by each of the methods. This is not to say that any one method is right or wrong, but the differences should be understood along with how one method correlates to another. Figure 9 compares the three primary deflection or penetration methods used for the softest, median, and hardest samples tested in this series. It must be understood that with such a hardness test comparisons curve, the results or trends are relative and subject to the particular samples selected.

The IRGL Test

We actually started with the original IRGL test, but soon realized that the force values of 110 and 220 N were too low, when compared with the forces used in the other three hardness tests. Four of the samples had less than 12% deflections at 220N and we needed much higher loads to achieve a 50% deflection. For these reasons, we decided to modify the IRGL parameters to cover about the same forces and deflections as measured by the standard IFD-ASTM test. We also changed the preflex conditions from a 330N force to two 75% deflection preflexes with a recovery period of 5 minutes. Figure 10 shows the IRGL height retained for nominal 50 mm blocks at the given series of forces applied. These data points were achieved by subtracting the raw penetration values from the reference height values for each sample. Such data has previously been reported and correlated to the H-point test [1]. By recalculating the penetration data, it can be changed to deflection resulting in a simulated force versus deflection curve as shown in Figure 11. One must keep in mind that these curves incorporate creep or thickness loss that occurs after a 60 seconds dwell time as specified in the test. Actually, the harder samples C & G should probably be tested at 600 N to obtain greater than 50% deflection.

Full curve presentation of these foam sample hardnesses gives a complete picture of their hardness performance. One can definitely see that sample A is so soft that it goes to higher deflections at high loads than the other samples. Another benefit of this data treatment is that it shows that certain pairs of samples have about the same force versus deflection profile, but these profiles have been achieved using a different system design in terms of density and graft/copolymer content; i.e. Samples I & E, F & B.

Additionally, Figure 12 can be generated using the actual slope in N/mm penetration for each of the target force measurements. The slope analysis figure gives one an appreciation for the complex performance behavior of different polyurethane foam systems. It also explains why standard deviations are higher at the lowest forces and then tend to level out at higher forces. This is believed to be due to force transference through the cell struts at low penetrations and then a reduction in force when cell buckling begins to take place. It is interesting that for sample A, the softest foam, the slope begins to increase at higher forces as the foam is compressed beyond 50% deflection resulting in significant compaction of the foam.

Individual hardness test points are of course all that is needed for a quality control check of flexible foam hardness. However, such data does not allow one to get the complete picture about a foam formulation's response in comparison to other formulations. We believe that methods that can give or generate a complete force versus deflection curve analysis such as the CPF-JCI or IRGL-IP Modified tests are useful for both system design / performance and specific quality check points for the manufacturing process.

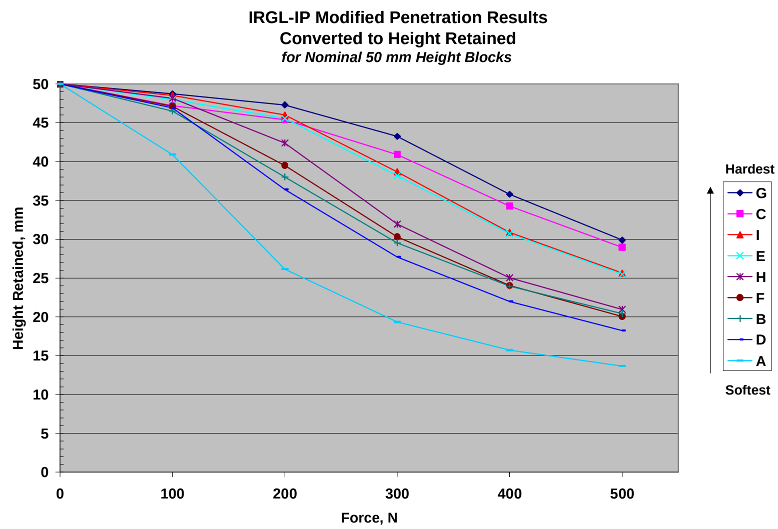


Figure 10.

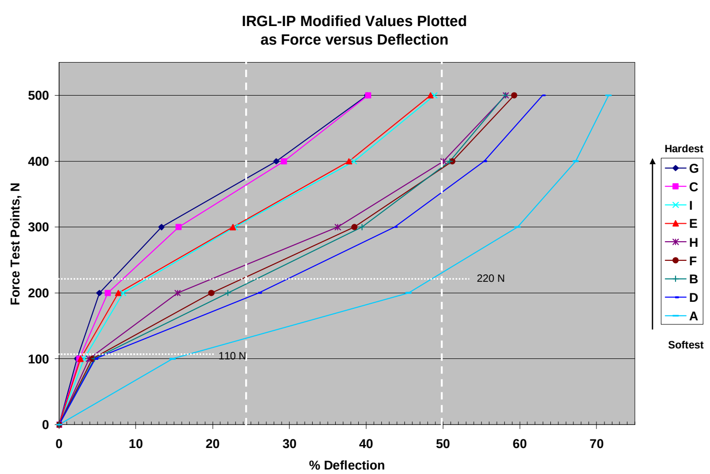


Figure 11.

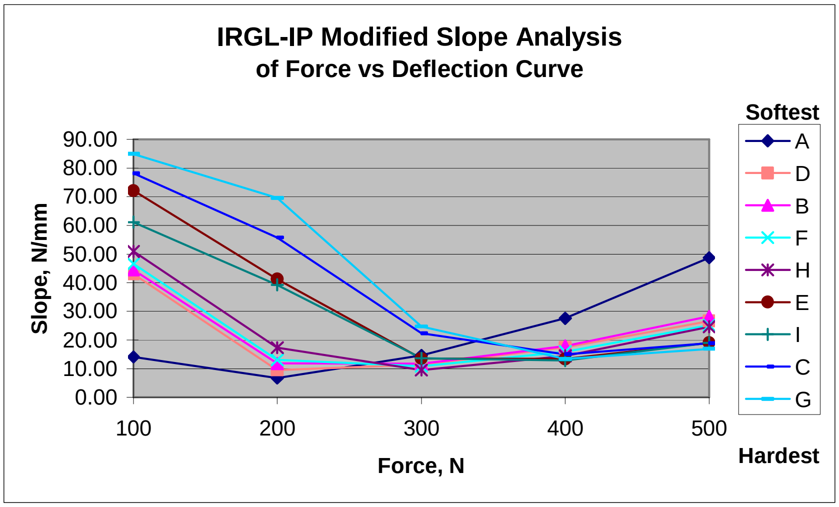


Figure 12.

Table 2.
Summary of Hardness Method Differences
On Nominal 50 mm Thickness Test Blocks
(Compared to IFD-ASTM as the Standard)

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	CPF	CPF STD	IFD-ASTM ~= IRGL-IP MOD.	IFD-IP MOD.
Deflection	*(~50%)*	*(~40%)*	**50%**	**50%**
Penetration	**25 mm**	**20 mm**	*(~50%)*	
Hardness Difference, N	**+ (50 – 100)**	**- (0 – 60)**	***Nominal Std.***	**- (20 – 80)**

Test Methods Summary

In summary, the hardness differences that can be expected between the four methods evaluated are shown in Table 2 above. The smaller hardness differences are for low hysteresis loss samples (20-30%) and the larger differences typically occur for the highest hysteresis loss samples (40-50%). Since these ranges of hardness differences are very much hysteresis based, it can easily be seen how much variability can be introduced by changes in test parameters and test speeds. This simple summary clearly emphasizes that part hardness is defined by the particular test and test points are not easily interchangeable. This also suggests that the Industry Panel goal to develop a simple, reliable, meaningful, and faster test method is a very worthy endeavor.

CONCLUSIONS

This study, while not satisfying the objectives of a 'gauge R&R', was far reaching in helping us understand the proper development of a test methodology toward an improved hardness test for automotive flexible foam parts. Rather than simply reporting the statistical variability, we thought it to be more important to uncover the sources of variability. Ultimately, we arrived at three main sources of variation: 1) The details of the method and the exact timing of the measurements; 2) The visco-elastic response of the flexible polyurethane foams being measured; 3) Interactions between the material and the test method.

We now fully appreciate the great influence flexible foam hysteresis loss has on the final hardness result. Hysteresis loss is such an integral part of the measurement that it should be reported as part of the method, as it is in the CPF-JCI method. The importance of hysteresis loss to seat design and performance has been reported in many other publications and it should not be ignored in the hardness testing method itself [4-6].

This exercise has also emphasized the need for a high level of detail in the test methods as hysteresis loss is normally incorporated in the preflex step and/or with the use of a dwell time at a given deflection or force. The full impact of this hysteresis loss is time dependent and the hardness value will eventually recover if given enough time. Accurate and reproducible hardness results cannot be achieved by manually run hardness methods, as was demonstrated in this exercise. Fortunately, computer software today can be completely automated to reproduce the exact test point measurement time especially when a hysteresis recovery slope is built into the measurement. We endorse fully programmable equipment and recommend that more detail needs to go into the industry methods themselves; i.e. ASTM, SAE, ISO.

The Industry Panel's objective of delivering an improved and perhaps speedier test methodology to measure the hardness of flexible foam used in automotive seating is only attainable with state-of-the-art equipment and software that is available today. We hope to build on the understanding that this study has provided and then carry out a more closely controlled 'gauge R&R' evaluation including OEM's and possibly Euromoulders in the near future.

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BIOGRAPHIES

Robert Lockwood

Robert Lockwood has 39 years of multi-discipline polyurethanes product development and technology with 25 of those years focused on MDI flexible foams. He has served in a variety of support and leadership positions over the past 25 years with Huntsman/ICI and prior worked for Upjohn at the Donald S Gilmore Research Laboratories. Robert is the author of nine industry papers and an inventor on eight U.S. patents. Robert received his B.S. in Chemistry from the University of Hartford, Connecticut.

Brent Hodge

Brent Hodge received his associates' degree in Metallurgical Engineering from Fanshawe College in London, Ontario in 1985. In 1988, Brent joined Johnson Controls and has spent the past 22 years in the automotive foam industry. During his tenure with Johnson Controls, he has worked in various functions including Quality, Program Management, and Product Engineering. He is currently the Engineering Subject Matter Technical Expert for seating foam within Johnson Controls North America, focusing primarily on product development.

G. R. Blair

Ron Blair received his degrees in Glasgow, Scotland. He continued his studies at the University of British Columbia before joining Royal Dutch Shell Plastics Laboratory in Holland. During his six years with Shell, he worked in various functions including fundamental research, plastics testing, and latterly, polyurethanes. In 1976, he joined Monsanto Canada, which became Woodbridge Foam Corporation in 1978. Ron has held various processing and chemistry positions and recently retired from managing the Woodbridge Corporate P3T Lab in 2006. He is currently a polyurethane consultant (ronblair@hotmail.com).

Mark Weierstall

Mark Weierstall has received an Associates Degree in General Studies from Macomb County Community College and is currently pursuing a Mechanical Engineering Degree. He has 25 years of experience in the automotive foam industry where his activities have mainly been focused on product development, physical testing, and specification development for seating and energy management foams. He currently manages Woodbridge's Corporate Comfort Laboratory in Troy, MI.

Asad Ali

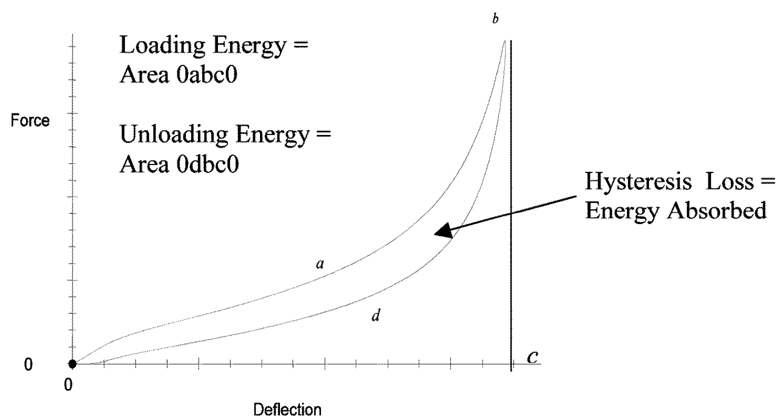
Asad Ali is Engineering Supervisor of Seat Systems Division at Lear Corporation. He has over 18 years of experience working with Polyurethane Systems in manufacturing, design / Engineering and applications for seat automotive interiors for performances as fit / functions. Asad has Bachelors and Masters Degree in Chemical Engineering from University of Detroit Mercy USA. He started his Polyurethane career as research scientist with Dr. Kurt Frisch at Polymer Technology Institute in 1989.

Roy Pask

Roy Pask has been with BASF Corporation since 1968 where currently he is Supervisor of Polymer Physics in the Urethanes R&D Department. With over 30 years of foam testing experience, Mr. Pask also represents BASF on a number of industry associations including the Center for the Polyurethanes Industries, the Polyurethane Foam Association, the Carpet Cushion Council, the Society of Automotive Engineers, the Molded Foam Industry Panel and the American Society for Testing and Materials, where he serves as subcommittee chairman for cellular material and urethane raw material standards. Roy did his undergraduate and graduate studies at Wayne State University in Detroit, Michigan.

APPENDIX

Figure 13
A Typical Force vs. Deflection Hysteresis Curve
For Polyurethane Flexible Foam *



$$\%Hysteresis\ Loss = [Loading\ Energy - Unloading\ Energy] \times 100/[Loading\ Energy]$$

"Hysteresis Loss for the purpose of this method is defined as the difference between the loading energy and the unloading energy expressed as a percentage of the loading energy."

* ASTM D 3574-08 Appendix X6.1 & X6.2 Suggested Method for Measuring Hysteresis Loss of Foams

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APPENDIX - Continued

Table 3
IFD – ASTM Hardness R&R Study

IFD - ASTM

Reference Block Height

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Average Absolute %Diff.	Block Ht. mm @ 4.5 N	Stdev
A	47.82	-0.49	48.40	0.71	48.15	0.19	48.29	0.47	48.26	0.42	47.43	-1.31	0.60	48.06	0.37
B	49.03	0.06	49.50	1.02	49.16	0.33	49.17	0.36	48.91	-0.18	48.22	-1.59	0.59	49.00	0.43
C	48.89	0.85	49.00	1.07	48.65	0.35	48.34	-0.30	48.57	0.19	47.43	-2.16	0.82	48.48	0.57
D	48.94	-0.43	49.50	0.71	49.28	0.26	49.38	0.46	49.18	0.06	48.63	-1.06	0.50	49.15	0.32
E	49.10	-0.32	49.60	0.69	49.42	0.33	49.38	0.24	49.30	0.08	48.76	-1.01	0.45	49.26	0.29
F	48.99	-0.47	49.60	0.77	49.29	0.14	49.40	0.37	49.28	0.12	48.76	-0.94	0.47	49.22	0.30
G	49.75	-0.28	50.20	0.62	49.92	0.06	50.06	0.35	49.93	0.08	49.47	-0.84	0.37	49.89	0.25
H	49.83	-0.49	50.40	0.65	50.04	-0.07	50.29	0.43	50.22	0.29	49.68	-0.79	0.45	50.08	0.28
I	49.82	-0.41	50.30	0.55	49.97	-0.11	50.22	0.39	50.2	0.35	49.63	-0.78	0.43	50.02	0.26
Absolute Average		0.42		0.76		0.205		0.37		0.197		1.17	0.52		0.34

25% IFD

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	Average Absolute %Diff.	25% IFD, N	Stdev
A	134.10	-1.27	133.80	-1.49	134.89	-0.69	139	2.34	133.21	-1.93	139.97	3.05	1.79	135.8	2.9
B	213.75	0.13	212.80	-0.32	211.53	-0.91	216	1.18	208.55	-2.31	218.25	2.23	1.18	213.5	3.4
C	309.69	2.81	294.80	-2.13	297.25	-1.32	304	0.92	293.51	-2.56	308.07	2.27	2.00	301.2	7.0
D	190.72	-0.85	189.60	-1.43	190.25	-1.09	195	1.38	192.18	-0.09	196.33	2.07	1.15	192.3	2.7
E	286.51	0.82	280.00	-1.48	281.52	-0.94	289	1.69	280.02	-1.47	288.11	1.38	1.29	284.2	4.1
F	219.72	-0.81	215.70	-2.62	219.54	-0.89	226	2.03	221.88	0.17	226.23	2.13	1.44	221.5	4.1
G	352.62	0.75	343.50	-1.86	346.76	-0.93	355	1.43	344.89	-1.46	357.28	2.08	1.42	350.0	5.7
H	241.76	-1.12	239.50	-2.04	242.06	-0.99	249	1.85	244.09	-0.16	250.52	2.47	1.44	244.5	4.4
I	315.26	-0.93	309.90	-2.62	315.35	-0.91	328	3.07	315.47	-0.87	325.43	2.26	1.78	318.2	6.9
Absolute Average		1.05		1.78		0.96		1.76		1.22		2.22	1.5		4.6

50% IFD

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	Average Absolute %Diff.	50% IFD, N	Stdev
A	237.44	0.82	226.00	-4.03	234.67	-0.35	242	2.76	231.32	-1.77	241.56	2.57	2.05	235.5	6.2
B	380.38	1.78	359.00	-3.94	372.15	-0.42	380	1.68	369.36	-1.16	381.39	2.05	1.84	373.7	8.7
C	563.83	4.58	504.00	-6.51	535.72	-0.63	546	1.28	535.20	-0.73	549.93	2.01	2.62	539.1	20.2
D	330.98	0.77	314.00	-4.40	327.16	-0.39	336	2.30	330.15	0.52	332.36	1.19	1.60	328.4	7.6
E	490.00	2.26	457.00	-4.63	477.51	-0.35	490	2.26	475.79	-0.70	484.70	1.15	1.89	479.2	12.4
F	375.27	0.33	355.00	-5.09	372.99	-0.28	384	2.66	376.15	0.56	380.87	1.82	1.79	374.0	10.2
G	587.84	1.57	555.00	-4.11	574.85	-0.68	591	2.11	573.80	-0.86	590.15	1.97	1.88	578.8	13.9
H	397.13	-0.43	385.00	-3.48	395.05	-0.96	408	2.29	399.41	0.14	408.58	2.44	1.62	398.9	8.8
I	520.02	-0.35	502.00	-3.80	518.92	-0.56	541	3.67	514.64	-1.38	534.40	2.41	2.03	521.8	14.0
Absolute Average		1.43		4.44		0.51		2.34		0.87		1.96	1.9		11.3

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APPENDIX - Continued

Table 4
IFD – IP Modified R&R Study *

IFD - IP Modified

Reference Block Height

	Lab 1		Lab 2		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 4 Labs		
Block ID	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Average Absolute %Diff.	Block Ht. mm @ 4.5 N	Stdev
A	47.58	-0.47	48.30	1.04	47.59	-0.44	~~46.79~~	~~-2.12~~	47.74	-0.13	~~50.87~~	~~6.42~~	0.52	47.80	0.34
B	49.01	0.12	49.30	0.72	48.83	-0.25	~~47.27~~	~~-3.43~~	48.66	-0.59	~~51.72~~	~~5.66~~	0.42	48.95	0.27
C	48.23	-0.27	48.70	0.70	48.34	-0.04	~~45.95~~	~~-4.99~~	48.17	-0.39	~~51.21~~	~~5.89~~	0.35	48.36	0.24
D	49.08	-0.06	49.40	0.60	49.07	-0.08	~~47.96~~	~~-2.35~~	48.88	-0.46	~~52.07~~	~~6.03~~	0.30	49.11	0.22
E	49.26	0.01	49.60	0.70	49.2	-0.12	~~48.01~~	~~-2.54~~	48.97	-0.58	~~52.19~~	~~5.95~~	0.35	49.26	0.26
F	49.09	-0.11	49.50	0.73	49.09	-0.11	~~48.18~~	~~-1.95~~	48.89	-0.51	~~52.12~~	~~6.06~~	0.36	49.14	0.26
G	49.82	-0.02	50.10	0.54	49.79	-0.08	~~48.82~~	~~-2.03~~	49.61	-0.44	~~52.80~~	~~5.96~~	0.27	49.83	0.20
H	49.95	-0.06	50.30	0.65	49.89	-0.18	~~49.28~~	~~-1.40~~	49.77	-0.42	~~52.98~~	~~6.01~~	0.32	49.98	0.23
I	49.89	-0.10	50.30	0.72	49.82	-0.24	~~49.28~~	~~-1.33~~	49.75	-0.38	~~52.95~~	~~6.03~~	0.36	49.94	0.25
Absolute Average		0.13		0.71		0.17		~~2.46~~		0.43		~~6.00~~	0.36		0.25

25% IFD

	Lab 1		Lab 2		Lab 3		~~Lab 4~~		Lab 5		Lab 6		Average 5 Labs		
Block ID	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	25% IFD, N	% Difference From AVE	Average Absolute %Diff.	25% IFD, N	Stdev
A	113.82	1.98	120.80	8.23	109.01	-2.33	~~138.00~~	~~23.64~~	105.48	-5.49	108.94	-2.39	4.09	111.61	5.93
B	175.60	1.01	187.60	7.92	172.06	-1.02	~~210.00~~	~~20.80~~	164.83	-5.18	169.11	-2.72	3.57	173.84	8.65
C	237.59	1.95	257.40	10.45	231.14	-0.82	~~287.00~~	~~23.15~~	216.54	-7.09	222.60	-4.49	4.96	233.05	15.80
D	165.67	1.57	173.60	6.43	159.18	-2.41	~~195.00~~	~~19.55~~	155.71	-4.54	161.38	-1.06	3.20	163.11	6.89
E	244.38	1.28	257.20	6.59	237.3	-1.66	~~281.00~~	~~16.46~~	229.83	-4.75	237.76	-1.46	3.15	241.29	10.28
F	197.66	1.76	200.50	3.22	189.34	-2.52	~~229.00~~	~~17.90~~	188.41	-3.00	195.29	0.54	2.21	194.24	5.24
G	314.61	2.29	313.20	1.83	304.15	-1.11	~~353.00~~	~~14.77~~	298.94	-2.81	306.94	-0.20	1.65	307.57	6.48
H	225.94	1.02	228.40	2.12	218.37	-2.37	~~262.00~~	~~17.14~~	220.60	-1.37	225.03	0.61	1.50	223.67	4.09
I	298.87	0.96	298.00	0.67	291.21	-1.62	~~341.00~~	~~15.20~~	292.73	-1.11	299.28	1.10	1.09	296.02	3.76
Absolute Average		1.54		5.27		1.76		~~18.73~~		3.93		1.62	2.82		7.46

50% IFD

	Lab 1		Lab 2		Lab 3		~~Lab 4~~		Lab 5		Lab 6		Average 5 Labs		
Block ID	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	50% IFD, N	% Difference From AVE	Average Absolute %Diff.	50% IFD, N	Stdev
A	219.09	3.32	219.00	3.28	206.26	-2.73	~~254.00~~	~~19.79~~	204.21	-3.69	211.66	-0.18	2.64	212.04	6.95
B	343.87	2.40	349.00	3.93	327.8	-2.39	~~399.00~~	~~18.82~~	325.22	-3.16	333.19	-0.78	2.53	335.82	10.27
C	489.77	3.11	501.00	5.47	461.17	-2.91	~~569.00~~	~~19.79~~	455.12	-4.19	468.00	-1.48	3.43	475.01	19.56
D	308.47	2.93	306.00	2.10	291.84	-2.62	~~350.00~~	~~16.79~~	290.47	-3.08	301.70	0.67	2.28	299.70	8.18
E	449.23	2.69	445.00	1.72	428.03	-2.16	~~506.00~~	~~15.66~~	425.33	-2.78	439.78	0.53	1.97	437.47	10.45
F	357.92	2.76	348.00	-0.08	338.52	-2.81	~~409.00~~	~~17.43~~	341.81	-1.86	355.22	1.99	1.90	348.29	8.34
G	556.69	2.79	540.00	-0.29	530.38	-2.07	~~630.00~~	~~16.33~~	532.33	-1.71	548.51	1.28	1.63	541.58	11.07
H	387.55	1.71	381.00	-0.01	371.56	-2.49	~~448.00~~	~~17.57~~	377.99	-0.80	387.14	1.60	1.32	381.05	6.69
I	512.78	1.64	500.00	-0.89	496.23	-1.64	~~584.00~~	~~15.76~~	499.76	-0.94	513.69	1.82	1.39	504.49	8.13
Absolute Average		2.59		1.98		2.42		~~17.55~~		2.47		1.15	2.12		9.96

* Data that is ‘strike-through’ (~~100.00~~) is exhibited for its variance, but is not included in the lab averages.

APPENDIX - Continued

Table 5
CPF Method R&R Study

CPF Method

Reference Block Height

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Average Absolute %Diff.	Block Ht. mm @ 4.5 N	Stdev
A	48.19	0.45	48.40	0.88	48.13	0.32	47.17	-1.68	47.86	-0.24	48.11	0.28	0.64	47.98	0.43
B	49.38	0.95	49.30	0.79	49.05	0.28	47.69	-2.50	49.05	0.28	49.01	0.20	0.83	48.91	0.62
C	48.73	0.92	48.80	1.07	48.55	0.55	46.57	-3.54	48.60	0.65	48.45	0.34	1.18	48.28	0.85
D	49.37	0.52	49.50	0.79	49.2	0.18	48.32	-1.61	49.05	-0.13	49.24	0.26	0.58	49.11	0.42
E	49.54	0.76	49.40	0.48	49.27	0.21	48.26	-1.84	49.13	-0.07	49.39	0.46	0.64	49.16	0.46
F	49.50	0.72	49.40	0.52	49.2	0.11	48.38	-1.55	49.08	-0.13	49.31	0.33	0.56	49.15	0.40
G	50.11	0.62	50.00	0.40	49.84	0.08	49.11	-1.38	49.79	-0.02	49.95	0.30	0.47	49.80	0.36
H	50.28	0.49	50.40	0.73	49.98	-0.11	49.48	-1.11	49.93	-0.21	50.14	0.21	0.48	50.03	0.33
I	50.34	0.56	50.40	0.68	50.01	-0.10	49.43	-1.25	49.91	-0.30	50.26	0.40	0.55	50.06	0.36
Absolute Average		0.67		0.70		0.22		1.83		0.23		0.31	0.66		0.47

15 mm Penetration

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	Penetration 15 mm, N	% Difference From AVE	Penetration 15 mm, N	% Difference From AVE	Penetration 15 mm, N	% Difference From AVE	Penetration 15 mm, N	% Difference From AVE	Penetration 15 mm, N	% Difference From AVE	Penetration 15 mm, N	% Difference From AVE	Average Absolute %Diff.	Penetration 15 mm, N	Stdev
A	172.09	0.66	167.57	-1.99	166.88	-2.39	176.00	2.94	169.56	-0.82	173.70	1.60	1.73	170.97	3.59
B	277.08	1.06	262.90	-4.11	277.05	1.05	284.00	3.59	258.39	-5.76	285.60	4.17	3.29	274.17	11.14
C	424.66	3.02	390.70	-5.22	425.66	3.26	427.00	3.59	374.17	-9.23	431.12	4.59	4.82	412.22	23.76
D	239.28	0.63	231.56	-2.62	234.78	-1.26	246.00	3.46	230.10	-3.23	244.97	3.02	2.37	237.78	6.76
E	359.50	0.94	342.96	-3.70	357.18	0.29	366.00	2.77	342.68	-3.78	368.57	3.49	2.49	356.15	11.13
F	273.61	0.42	264.41	-2.96	268.51	-1.45	283.00	3.86	264.13	-3.06	281.18	3.20	2.49	272.47	8.22
G	430.16	0.36	417.93	-2.50	427.29	-0.31	438.00	2.19	415.81	-2.99	442.57	3.25	1.93	428.63	10.63
H	288.88	0.07	282.00	-2.31	280.84	-2.71	300.00	3.93	285.16	-1.21	295.11	2.23	2.08	288.67	7.59
I	376.83	-0.11	367.00	-2.71	369.31	-2.10	393.00	4.18	370.21	-1.86	387.05	2.60	2.26	377.23	10.60
Absolute Average		0.81		3.12		1.65		3.39		3.55		3.13	2.61		10.38

20 mm Penetration

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	Penetration 20 mm, N	% Difference From AVE	Penetration 20 mm, N	% Difference From AVE	Penetration 20 mm, N	% Difference From AVE	Penetration 20 mm, N	% Difference From AVE	Penetration 20 mm, N	% Difference From AVE	Penetration 20 mm, N	% Difference From AVE	Average Absolute %Diff.	Penetration 20 mm, N	Stdev
A	223.49	1.69	210.98	-4.01	216.86	-1.33	228.00	3.74	215.75	-1.84	223.62	1.75	2.39	219.78	6.30
B	357.78	1.47	335.97	-4.71	355.54	0.84	368.00	4.37	332.66	-5.65	365.56	3.68	3.45	352.59	14.93
C	557.93	3.30	511.58	-5.29	554.31	2.63	565.00	4.61	491.90	-8.93	560.04	3.69	4.74	540.13	30.57
D	305.83	1.14	289.74	-4.18	300.41	-0.65	315.00	4.18	292.66	-3.21	310.58	2.72	2.68	302.37	9.97
E	455.19	1.10	431.53	-4.16	452.14	0.42	466.00	3.50	433.67	-3.68	462.96	2.82	2.61	450.25	14.58
F	346.55	0.82	328.81	-4.34	340.45	-0.95	359.00	4.45	333.72	-2.91	353.77	2.92	2.73	343.72	11.62
G	534.66	0.60	511.97	-3.67	531.4	-0.01	547.00	2.92	516.76	-2.77	547.08	2.94	2.15	531.48	14.78
H	355.45	0.36	341.28	-3.64	347.01	-2.02	370.00	4.47	350.06	-1.16	361.28	2.00	2.28	354.18	10.36
I	464.49	0.30	445.20	-3.87	454.91	-1.77	485.00	4.73	455.34	-1.68	473.68	2.28	2.44	463.10	14.43
Absolute Average		1.20		4.21		1.18		4.11		3.54		2.76	2.83		14.17

25 mm Penetration

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Average Absolute %Diff.	Penetration 25 mm, N	Stdev
A	300.44	2.65	277.51	-5.19	291.88	-0.28	307.00	4.89	282.46	-3.50	296.88	1.43	2.99	292.7	11.1
B	476.60	2.03	438.85	-6.05	472.97	1.26	492.00	5.33	438.54	-6.11	483.62	3.54	4.05	467.1	22.9
C	755.06	4.01	677.96	-6.61	744.31	2.53	772.00	6.34	657.20	-9.47	749.28	3.21	5.36	726.0	46.6
D	403.71	1.99	373.25	-5.70	394.69	-0.29	415.00	4.84	382.12	-3.46	406.21	2.62	3.15	395.8	15.7
E	592.85	0.98	550.96	-6.15	587.82	0.13	631.00	7.48	561.32	-4.39	598.51	1.95	3.51	587.1	28.5
F	454.23	1.52	420.32	-6.06	444.68	-0.61	472.00	5.50	433.67	-3.07	459.57	2.72	3.25	447.4	18.6
G	688.04	1.18	645.72	-5.04	679.38	-0.09	708.00	4.12	660.42	-2.88	698.41	2.71	2.67	680.0	23.4
H	453.58	1.09	426.80	-4.87	441.51	-1.60	473.00	5.42	443.31	-1.20	453.83	1.15	2.56	448.7	15.5
I	595.14	0.84	559.46	-5.20	580.43	-1.65	624.00	5.73	578.89	-1.91	603.04	2.18	2.92	590.2	22.4
Absolute Average		1.81		5.65		0.94		5.52		4.00		2.39	3.4		22.8

Hysteresis Loss, %

	Lab 1		Lab 2		Lab 3		Lab 4		Lab 5		Lab 6		Average 6 Labs		
Block ID	Hysteresis Loss, %	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Penetration 25 mm, N	% Difference From AVE	Average Absolute %Diff.	Penetration 25 mm, N	Stdev
A	32.79	-1.26	34.80	4.79	35.95	8.26	29.60	-10.87	32.61	-1.80	33.50	0.88	4.64	33.2	2.2
B	40.72	-1.59	44.20	6.82	43.91	6.12	38.10	-7.92	38.81	-6.21	42.53	2.78	5.24	41.4	2.6
C	49.14	-0.62	53.00	7.19	52.03	5.22	46.00	-6.97	46.61	-5.74	49.90	0.92	4.44	49.4	2.8
D	32.56	-0.94	35.10	6.79	35.46	7.88	29.60	-9.94	30.64	-6.78	33.85	2.99	5.89	32.9	2.4
E	35.98	-1.13	38.80	6.62	39.36	8.16	33.00	-9.32	34.05	-6.43	37.15	2.09	5.62	36.4	2.5
F	27.98	-1.21	30.30	6.98	30.64	8.18	25.40	-10.32	26.45	-6.61	29.17	2.99	6.05	28.3	2.1
G	30.01	-2.03	33.30	8.71	32.6	6.42	27.70	-9.58	28.66	-6.44	31.53	2.93	6.02	30.6	2.2
H	19.94	-2.89	22.40	9.09	22.38	8.99	18.10	-11.85	18.96	-7.66	21.42	4.32	7.47	20.5	1.8
I	19.43	-1.96	21.70	9.49	21.48	8.38	17.40	-12.20	18.43	-7.01	20.47	3.29	7.06	19.8	1.7
Absolute Average		1.51		7.39		7.51		9.89		6.08		2.58	5.8		2.3

APPENDIX – Continued

Table 6
IRGL – IP Modified R&R Study* / **

IRGL - IP Modified
Reference Block Height

	Lab 1		~~Lab 2~~		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 3 Labs		
Block ID	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Block Ht. mm @ 4.5 N	% Difference From AVE	Average Absolute %Diff.	Block Ht. mm @ 4.5 N	Stdev
A	48.08	0.36	~~47.96~~	~~0.10~~	47.65	-0.54			47.99	0.18			0.18	47.91	0.23
B	48.80	0.28	~~49.24~~	~~1.19~~	48.42	-0.50			48.76	0.21			0.17	48.66	0.21
C	48.15	-0.08	~~49.03~~	~~1.73~~	47.96	-0.48			48.46	0.56			0.19	48.19	0.25
D	49.16	0.17	~~49.42~~	~~0.70~~	48.84	-0.48			49.23	0.32			0.16	49.08	0.21
E	49.24	0.13	~~49.53~~	~~0.73~~	48.92	-0.52			49.37	0.39			0.17	49.18	0.23
F	49.27	0.24	~~49.72~~	~~1.15~~	48.91	-0.49			49.28	0.25			0.16	49.15	0.21
G	49.86	0.08	~~50.13~~	~~0.62~~	49.7	-0.24			49.90	0.17			0.08	49.82	0.11
H	50.14	0.25	~~50.46~~	~~0.89~~	49.78	-0.47			50.13	0.23			0.16	50.02	0.20
I	50.12	0.08	~~50.39~~	~~0.62~~	49.94	-0.28			50.18	0.20			0.09	50.08	0.12
Absolute Average		0.19		~~0.86~~		0.44				0.28			0.15	49.12	0.20

IRGL - IP Modified
100 N

	Lab 1		~~Lab 2~~		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 3 Labs		
Block ID	Penetration mm @100 N	% Difference From AVE	Penetration mm @100 N	% Difference From AVE	Penetration mm @100 N	% Difference From AVE	Penetration mm @100 N	% Difference From AVE	Penetration mm @100 N	% Difference From AVE	Penetration mm @100 N	% Difference From AVE	Average Absolute %Diff.	Penetration mm @100 N	Stdev
A	5.34	-11.78	~~7.51~~	~~24.04~~	5.72	-5.50			7.10	17.27			5.76	6.05	0.93
B	2.13	-4.71	~~2.98~~	~~33.45~~	2.33	4.24			2.25	0.47			1.57	2.24	0.10
C	1.46	-2.85	~~2.63~~	~~74.67~~	1.77	17.77			1.28	-14.92			5.92	1.50	0.25
D	2.20	-3.12	~~2.71~~	~~19.33~~	2.29	0.84			2.32	2.29			1.04	2.27	0.06
E	1.40	-3.80	~~1.81~~	~~24.58~~	1.58	8.57			1.39	-4.77			2.86	1.46	0.11
F	2.02	-2.95	~~2.57~~	~~23.43~~	2.08	-0.07			2.14	3.02			1.01	2.08	0.06
G	1.15	-5.15	~~1.56~~	~~28.50~~	1.31	8.05			1.18	-2.90			2.68	1.21	0.09
H	1.85	-3.05	~~2.27~~	~~18.96~~	1.91	0.10			1.96	2.95			1.02	1.91	0.06
I	1.54	-3.06	~~1.93~~	~~21.43~~	1.59	0.09			1.64	2.97			1.02	1.59	0.05
Absolute Average		4.50		~~29.82~~		5.02				5.73			2.54		0.19

IRGL - IP Modified
200 N

	Lab 1		~~Lab 2~~		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 3 Labs		
Block ID	Penetration mm @200 N	% Difference From AVE	Penetration mm @200 N	% Difference From AVE	Penetration mm @200 N	% Difference From AVE	Penetration mm @200 N	% Difference From AVE	Penetration mm @200 N	% Difference From AVE	Penetration mm @200 N	% Difference From AVE	Average Absolute %Diff.	Penetration mm @200 N	Stdev
A	20.63	-2.91	~~23.37~~	~~9.98~~	21.27	0.10			21.84	2.81			0.97	21.25	0.61
B	10.29	-2.47	~~12.58~~	~~19.27~~	10.63	0.76			10.73	1.71			0.82	10.55	0.23
C	4.04	5.37	~~5.93~~	~~54.54~~	4.39	14.50			3.07	-19.88			6.63	3.83	0.68
D	13.43	2.53	~~15.08~~	~~15.12~~	13.06	-0.30			12.81	-2.23			0.84	13.10	0.31
E	4.32	3.63	~~5.35~~	~~28.41~~	4.38	5.07			3.81	-8.70			2.90	4.17	0.32
F	10.11	3.96	~~11.65~~	~~19.79~~	9.29	-4.47			9.77	0.51			1.49	9.72	0.41
G	2.73	0.69	~~3.44~~	~~26.80~~	2.79	2.90			2.61	-3.59			1.20	2.71	0.09
H	7.80	3.34	~~8.82~~	~~16.87~~	7.1	-5.93			7.74	2.59			1.98	7.55	0.39
I	4.12	0.72	~~4.72~~	~~15.36~~	3.97	-2.95			4.18	2.24			0.98	4.09	0.11
Absolute Average		2.85		~~22.90~~		4.11				4.92			1.98		0.35

* Data that is 'strike-through' (~~100.00~~) is exhibited for its variance, but is not included in the lab averages.

** Raw data is shown as penetration in mm for the forces measured. Actual IRGL would be Ref. block height minus the penetration value.

APPENDIX – Continued

Table 7

IRGL – IP Modified R&R Study * / **

IRGL - IP Modified

300 N

	Lab 1		~~Lab 2~~		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 3 Labs		
Block ID	Penetration mm @300 N	% Difference From AVE	Penetration mm @300 N	% Difference From AVE	Penetration mm @300 N	% Difference From AVE	Penetration mm @300 N	% Difference From AVE	Penetration mm @300 N	% Difference From AVE	Penetration mm @300 N	% Difference From AVE	Average Absolute %Diff.	Penetration mm @300 N	Stdev
A	28.16	-1.24	~~30.43~~	~~6.71~~	28.73	0.75			28.65	0.49			0.41	28.51	0.31
B	19.60	-0.03	~~22.10~~	~~12.74~~	19.98	1.91			19.24	-1.88			0.64	19.61	0.37
C	10.71	9.25	~~13.65~~	~~39.18~~	11.15	13.73			7.55	-22.98			7.66	9.80	1.96
D	22.84	2.38	~~24.54~~	~~10.00~~	22.57	1.17			21.51	-3.56			1.19	22.31	0.70
E	13.53	6.33	~~15.25~~	~~19.87~~	13.47	5.85			11.18	-12.18			4.06	12.73	1.34
F	20.14	3.46	~~21.88~~	~~12.39~~	19.3	-0.85			18.96	-2.61			1.15	19.47	0.61
G	8.44	10.97	~~10.20~~	~~34.08~~	7.72	1.50			6.66	-12.47			4.16	7.61	0.90
H	18.69	2.57	~~19.92~~	~~9.32~~	17.78	-2.43			18.20	-0.14			0.86	18.22	0.46
I	11.68	2.48	~~12.76~~	~~11.95~~	11.02	-3.31			11.49	0.83			1.10	11.40	0.34
Absolute Average		4.30		~~17.36~~		3.50				6.35			2.36		0.78

IRGL - IP Modified

400 N

	Lab 1		~~Lab 2~~		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 3 Labs		
Block ID	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Average Absolute %Diff.	Penetration mm @400 N	Stdev
A	31.95	-0.81	~~33.71~~	~~4.65~~	32.4	0.58			32.28	0.23			0.27	32.21	0.23
B	25.30	0.15	~~27.79~~	~~10.02~~	25.68	1.65			24.81	-1.80			0.60	25.26	0.44
C	16.96	4.91	~~19.96~~	~~23.44~~	17.34	7.26			14.20	-12.17			4.06	16.17	1.72
D	28.30	1.49	~~29.84~~	~~7.02~~	28.1	0.78			27.25	-2.27			0.76	27.88	0.56
E	20.56	3.26	~~22.23~~	~~11.67~~	20.53	3.11			18.64	-6.38			2.13	19.91	1.10
F	26.19	2.10	~~27.76~~	~~8.22~~	25.53	-0.47			25.23	-1.63			0.70	25.65	0.49
G	16.05	5.95	~~17.97~~	~~18.61~~	15.28	0.87			14.12	-6.82			2.27	15.15	0.97
H	25.47	1.41	~~26.56~~	~~5.75~~	24.78	-1.34			25.10	-0.07			0.47	25.12	0.35
I	19.43	1.30	~~20.56~~	~~7.19~~	18.83	-1.83			19.28	0.52			0.61	19.18	0.31
Absolute Average		2.38		~~10.73~~		1.99				3.54			1.32		0.69

IRGL - IP Modified

500 N

	Lab 1		~~Lab 2~~		Lab 3		~~Lab 4~~		Lab 5		~~Lab 6~~		Average 3 Labs		
Block ID	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Penetration mm @400 N	% Difference From AVE	Average Absolute %Diff.	Penetration mm @400 N	Stdev
A	34.08	-0.66	~~35.61~~	~~3.79~~	34.5	0.57			34.34	0.09			0.22	34.31	0.21
B	29.13	0.49	~~31.36~~	~~8.19~~	29.5	1.76			28.34	-2.25			0.75	28.99	0.59
C	21.63	2.85	~~24.54~~	~~16.66~~	21.96	4.41			19.50	-7.26			2.42	21.03	1.33
D	31.59	0.74	~~32.80~~	~~4.60~~	31.48	0.39			31.00	-1.14			0.38	31.36	0.31
E	25.38	2.01	~~26.95~~	~~8.33~~	25.37	1.97			23.89	-3.98			1.33	24.88	0.86
F	29.85	1.28	~~31.16~~	~~5.72~~	29.36	-0.38			29.21	-0.90			0.43	29.47	0.34
G	21.78	4.03	~~23.54~~	~~12.43~~	21.01	0.35			20.02	-4.38			1.46	20.94	0.88
H	29.39	0.82	~~30.36~~	~~4.15~~	28.9	-0.86			29.16	0.04			0.29	29.15	0.25
I	24.62	0.77	~~25.65~~	~~4.98~~	24.15	-1.15			24.53	0.39			0.38	24.43	0.25
Absolute Average		1.52		~~7.65~~		1.32				2.27			0.85		0.56

* Data that is 'strike-through' (~~100.00~~) is exhibited for its variance, but is not included in the lab averages.

** Raw data is shown as penetration in mm for the forces measured. Actual IRGL would be Ref. block height minus the penetration value.