Report, Puncture Resistance Testing, 6 and 9 Mar 2012

Executive Summary

Puncture resistance testing IAW ASTM 2412-5 was conducted on specimens of the Kingetics orthotic and on specimens of commercially available, regulation military boot sole assemblies over two separate days of testing. The Kingetics orthotic was tested in two parts, the Spring Plate and the Heel Cradle. The military boot assemblies were prepared by separating the upper portion of the boot from the sole assembly.

The Kingetics Orthotic Spring Plate puncture resistance averaged approximately three times more than the military boot sole assemblies. The Sport Model Heel Cradle puncture resistance averaged approximately five times more than the military boot sole assemblies. The Safety Model Heel Cradle puncture resistance averaged approximately ten times more than the military boot sole assemblies.

Additional testing indicated that the puncture resistance of the entire Spring Plate was consistent across the entire plate, not just in the test area in the center of the specimen, as narrowly defined by the ASTM.

Purpose

The purpose of this testing was to document the puncture resistance of the Kingetics orthotic, in two models, Sport and Safety. A further goal was to compare the orthotics' puncture resistance with that of standard issue, commercially available, military footwear. The American Society for Testing and Materials (ASTM) 2412-05, *Standard Test Methods for Foot Protection*, was used as the reference document for this testing process.

Equipment and Test Setup

All testing was conducted at the Composite and Polymer Experimentation (CAPE) Laboratory, South Dakota School of Mines and Technology (SDSM&T), Rapid City, SD, on two separate days, 6 and 9 Mar 12. The dates of the testing were based upon the availability of the required instrumentation, equipment, and technical support to conduct the tests.

The test probe and specimen test fixture were constructed IAW ASTM 2412-5 specifications by an engineer at the CAPE Lab. The test probe and fixture were all designed to fit the test device: the MTS 810 system, the load frame, its related hydraulics, and computerized controls.

Test Narrative

The computerized test equipment protocol was set up for the test by an engineer at CAPE Lab. The actual testing was conducted by a CAPE technician. The use of the test protocol allowed the puncture resistance testing to be repeated over and over again, using exactly the same settings each time, all IAW the ASTM specifications.

The specimens to be tested consisted of the orthotics developed by Kingetics, in two models, the Sport and the Safety models. It is noted that the two models differ in the construction of the Heel Cradle only, and that the Spring Plate in both models is of the same construction.

In addition to the tests on the orthotics, puncture resistance testing was performed on regulation, standard issue, and commercially available military footwear. The specific manufacturer was Belleville, and the model tested was the DES 390, in three different boot sizes. The boots were prepared for the testing by cutting away the upper portion of the boot from the sole assembly, so that just the sole assembly was secured to the test fixture and tested.

The test process began by placing the specimen on the test fixture's bed and clamping it down. The computerized controls were then used to start the test sequence. The test probe was lowered at the appropriate rate IAW the ASTM and the applied force (in Newtons) was measured and recorded. The distance that the probe was extended was also recorded (in mm). Each trial's data was captured automatically by the instrumentation and later downloaded as text files for further processing and review. Each specimen tested had a unique test code, and therefore, so did each penetration trial.

Each trial was recorded as a set of time elapsed, applied force, and probe extension measurements. The instrumentation which measured the applied force also compared and analyzed the readings. The purpose of the comparison was to find and record the "minimum force required for puncture to occur" (Para 11.6, ASTM 2412-5). This occurrence was further defined as the applied force necessary so that the probe tip was extended through the specimen and the full diameter of the probe completely penetrated the specimen. This was interpreted and recorded by the instrumentation when the applied force rapidly decreased by one-half the force measured. A review of the amount of probe extension, along with a comparison of the thickness of the specimen, confirmed that the test probe was penetrating the specimen IAW the ASTM.

Two sets of graphs can be developed and analyzed using the data recorded by the instrumentation. The first set is the detailed track of the probe, measured by applied force (in Newtons) and by the amount of probe extension (in mm). The peak of the graph represents the "minimum force required for penetration to occur". The second set of data is the cumulative recording of "minimum force required", by specimen penetration trial. The second set of data may best be described as a summary of all the penetration trials made on each specimen.

The second set of data, the summary set, is most appropriate for use in this report. The first set of data, the detailed set, requires additional analysis and may be useful in any forthcoming report. Only a representative sample of the graph generated by the detailed data set is provided for this report, as background information only.

The testing was conducted over two days at the CAPE Lab, 6 and 9 Mar 12. Additional follow up testing may be required and will be scheduled at a later date. The first day of testing provided more penetration trials per specimen, but was limited in the number of specimens tested. The second day of testing limited the number of penetration trials to the minimum requirements of the ASTM, but allowed the completion of all the desired testing on each specimen for all tested specimens.

The ASTM requires that the penetration trials not be placed within one inch of the edge of the specimen. This restricts the placement of the penetration trials to an area roughly in the center of each specimen. The appropriate limits were marked on each specimen and the tests were conducted IAW the ASTM. This restriction applied to both the orthotic specimens and the boot sole specimens and this group of testing was called Part 1 of the testing.

It was observed that the orthotics' Spring Plate construction was consistent all across the entire orthotic and that the puncture resistance should not differ whether conducted inside or outside of the restricted testing area as prescribed by the ASTM, or within the one inch margin of the orthotic's edge. This same observation was made of the Heel Cradle. These observations resulted in Part 2 of the puncture resistance testing. Part 2 testing consisted of limited testing outside the limited area prescribed by the ASTM and within the one inch margin of the specimen edge. The purpose of Part 2 of the testing was to document the presence or absence of any degradation of puncture resistance at the edges of the orthotics. Part 2 testing was conducted only on the orthotics and not on the boot sole specimens.

During the testing process, it was observed that the test probe was jeopardized when applied against the fulcrums of both the Spring Plate and the Heel Cradle. In the case of the Spring Plate fulcrum, the test probe had difficulty finding purchase on the smooth, rounded surface. The concern was that the probe would slip off the fulcrum's surface and either bend or break. In the case of the Heel Cradle, the probe was able to penetrate the fulcrum, but, in one case, the fulcrum split off a fragment of the fulcrum. In a second trial, the fulcrum was completely split off the Heel Cradle.

When testing the Safety Heel Cradles, it was noted that the test probe was able to penetrate the material, but the process was slower and more difficult than with the thinner and lighter Sport Model Heel Cradle.

Based the time constraints due to equipment and personnel availability, the difficulties experienced with the fulcrums and the Safety Heel Cradles, and the need to complete all of the testing, any further testing of the fulcrum and the Safety Heel Cradles was suspended for this series of testing.

On 6 Mar 12, Part 1 of the testing, the ASTM-prescribed penetration trials, were performed on two Sport Model sets of orthotics. On 9 Mar 12, Part 1 of the testing was completed on the remaining one set of Sport Model orthotic, three sets of Safety Model orthotics, as well as the three sets of boot soles. Part 2 of the testing was completed on a limited number of orthotics.

A series of photographs were taken throughout the testing process to document the instrumentation, equipment, and handling of the specimens.

Figure 1: The MTS 810 Hydraulic Test Frame

Figure 2: The test fixture, on which the test specimen is mounted

Figure 3: The Hydraulics Controller

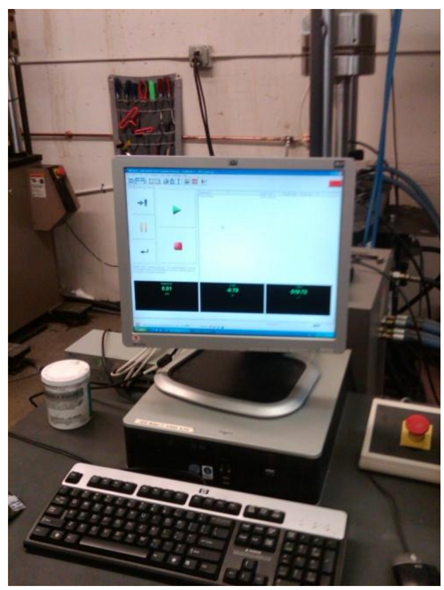

Figure 4: The computer test control station.

Figure 5: The Spring Plate, locked onto the test fixture, with several trials completed

Figure 6: The Heel Cradle, locked onto the test fixture, with several trials completed

As shown in Figures 5 and 6, the test specimens were mounted in the MTS 810 test fixture and puncture testing on the specimens was conducted. Each hole in the specimen represents a penetration trial. The area outlined in black on the Spring Plates and in white on the Heel Cradles represents the area prescribed by the ASTM in which testing may be conducted. This testing was called Part 1 testing. Part 2 testing consisted of penetration trial outside the marked areas, and within the one inch margin from the specimens' edges.

Test Results

Figures 7 and 8 show test specimens with the penetration trials completed.

Figure 7: The Spring Plate

Figure 8: The Heel Cradle

The test narrative reported issues with testing the fulcrums on both the Spring Plates and on the Heel Cradles. Specifically, the fulcrums either broke in pieces or broke completely off the test specimen. Figures 9 and 10 serve to document these issues on the Heel Cradles.

Figure 9: A sliver has broken off the fulcrum as a result of the penetration trial

Figure 10: The fulcrum has separated from the Heel Cradle completely

As stated in the test narrative, the tests involving the fulcrums were terminated to preclude any damage to the test probe.

As reported in the test narrative, the computerized test protocol identically reproduced the penetration trials repeatedly. A detailed data set was generated for each penetration trial. Figures 12 and 13 are representative samples of the detailed data set.

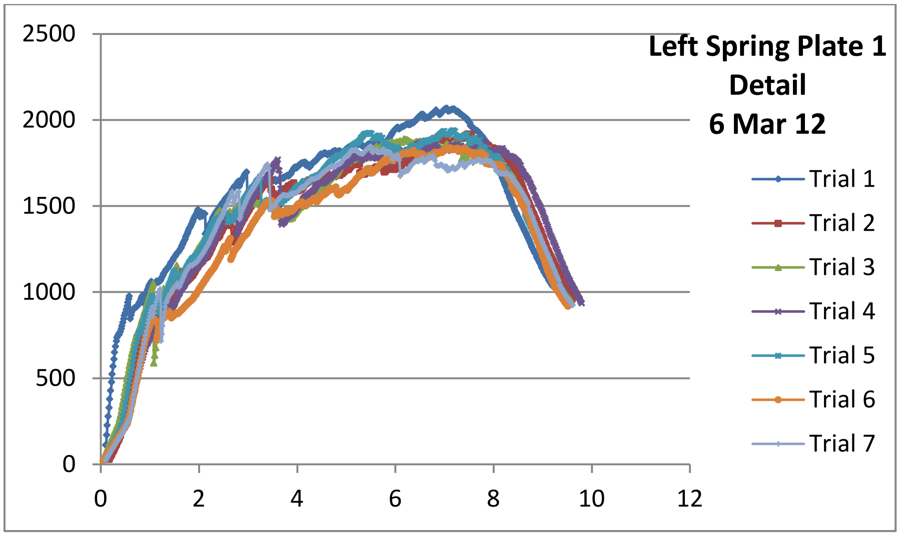

Figure 12: Exemplar detailed penetration trials 1 through 7 on a left Spring Plate (Sport Model)

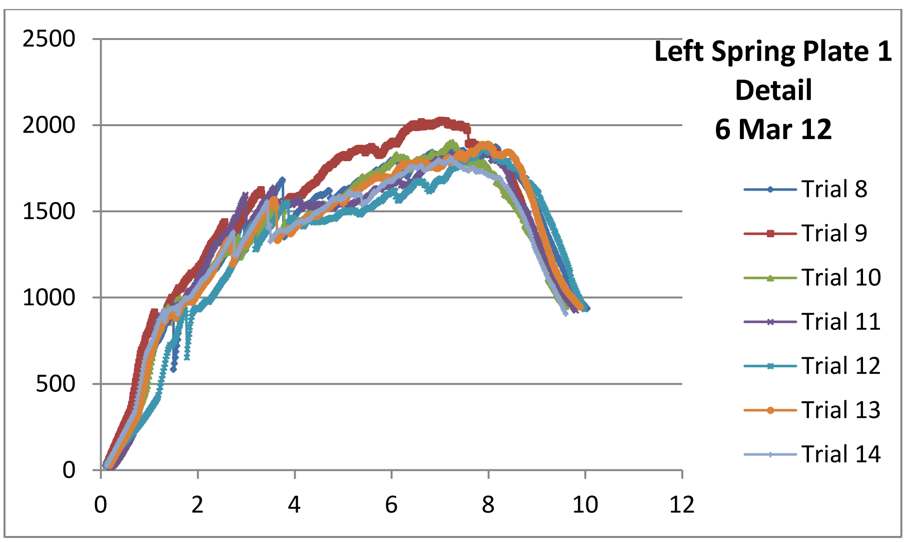

Figure 13: Exemplar detailed penetration trials 8 through 14 on a left Spring Plate (Sport Model)

Additionally, a summary data set was generated for each specimen, capturing the "minimum force necessary" to puncture the specimen. Figures 14 through 16 are examples of the summarized penetration trial results, including Spring Plates, Heel Cradles, and Boot Sole Assemblies.

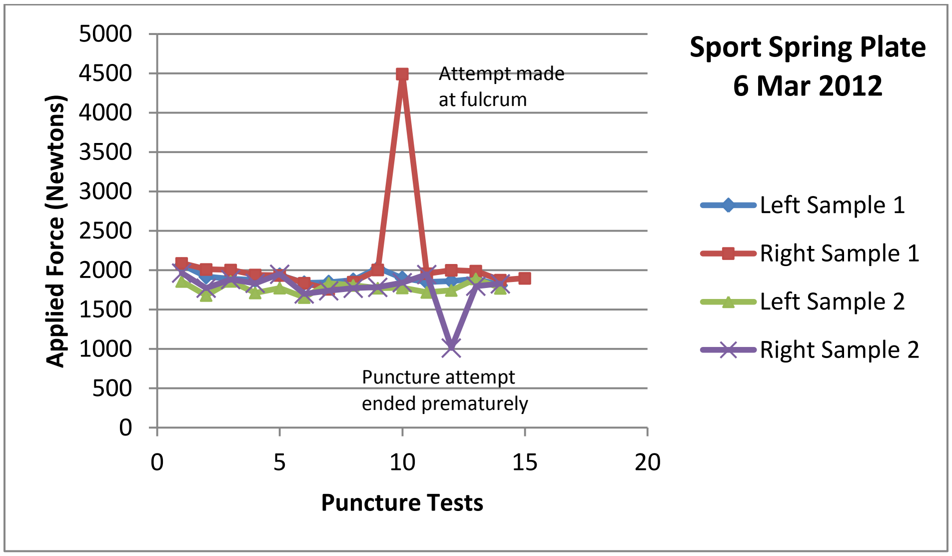

Figure 14: Example Summary Chart, Spring Plate penetration trials

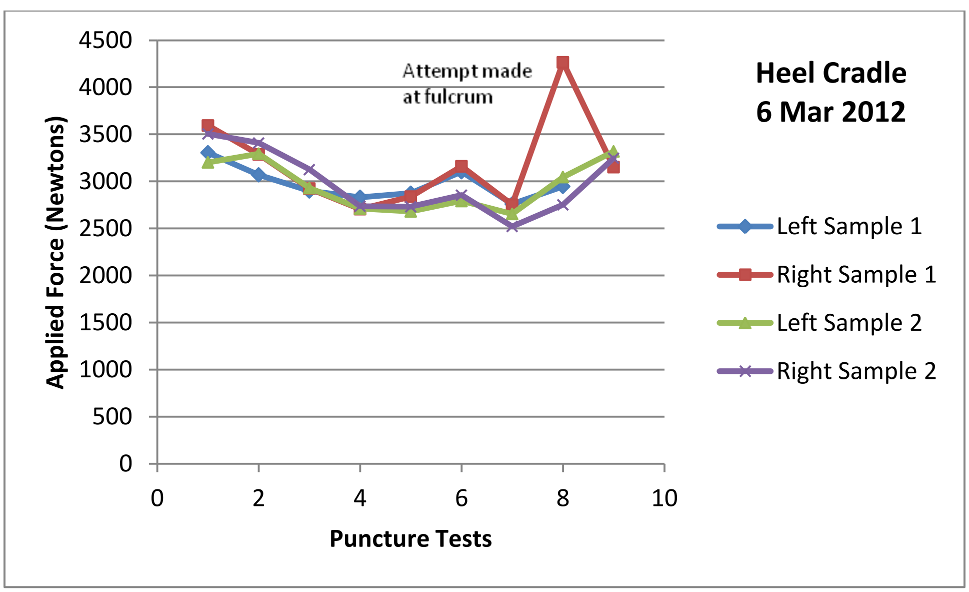

Figure 15: Example Summary Chart, Heel Cradle penetration trials

The boot sole assemblies were tested in the same manner as the Kingetics orthotics, using the same testing protocols and equipment.

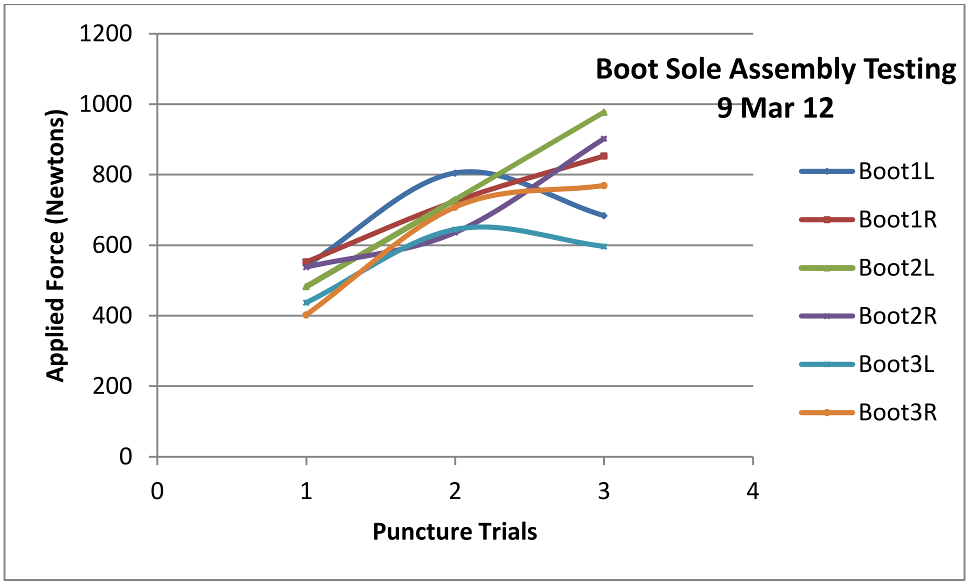

Figure 16: Example Summary Chart, Boot Sole Assembly penetration trials

Additionally, a summary data set was generated for each specimen, capturing the "minimum force necessary" to puncture the specimen. Figures 17 through 18 are examples of the summarized Part 2 penetration trial results, including Spring Plates and Heel Cradles.

Figure 17 documents what is believed to be an error in sample marking. The specimen labeled "SAF1RH1" is the only penetration trial of a Safety Model Heel Cradle made before cancelling further testing of the Safety Model Heel Cradles to preclude damage to the test probe. The specimens marked "SAF2LH1" and "SAF2RH1", respectively, are actually Sport Model Heel Cradle Part 2 penetration trials, and were incorrectly marked prior to the testing. This marking error will be corrected in future testing. The data itself is deemed to be correct for a Sport Model Heel Cradle.

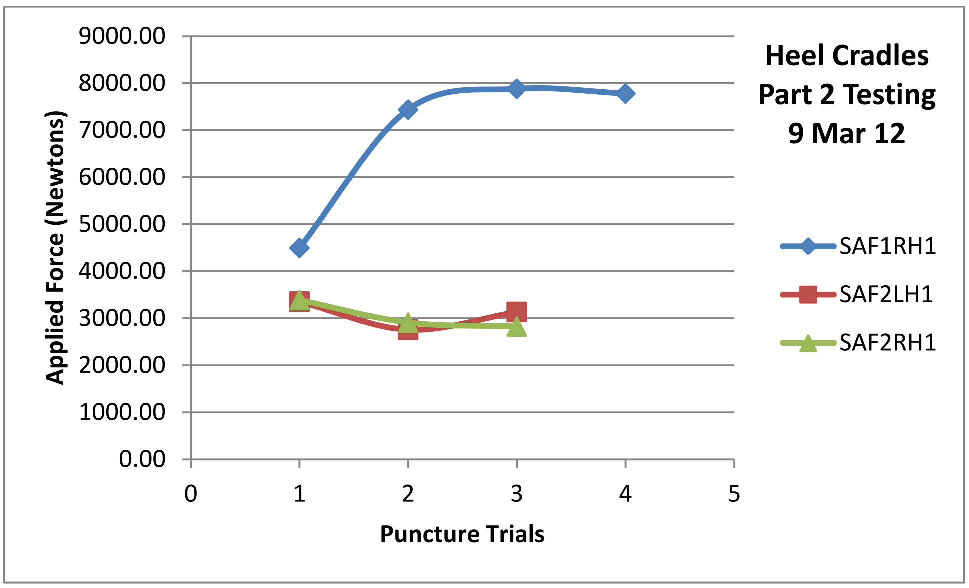

Figure 17: Example Summary Chart, Heel Cradle, Part 2 penetration trials

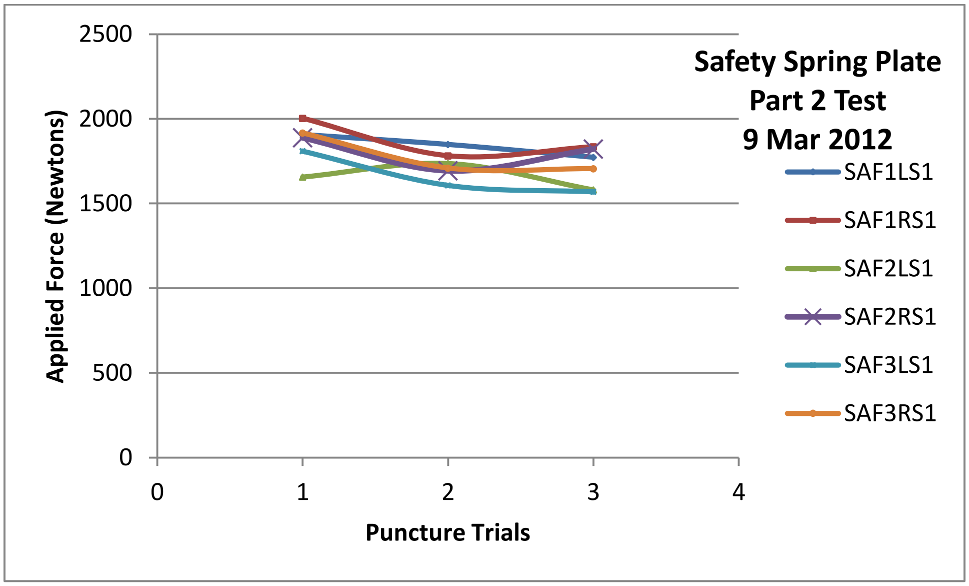

Figure 18: Example Summary Chart, Spring Plate Part 2 penetration trials

Table 1: Summary of Puncture Resistance Testing Results, Kingetics Orthotics and Commercial Military Boot Sole Assembly, 6 and 9 March 2012

Test Specimen	Type Test	Date of Test	Number of Trials	Average Applied Force (Newtons)
Safety/Sport Spring Plate	ASTM Standard	6 Mar 12	55	1861.49
Safety/Sport Spring Plate	ASTM Standard	9 Mar 12	18	1769.12
Safety/Sport Spring Plate	**ASTM Standard**	**Both Test Days**	**Average**	**1815.31**
Safety/Sport Spring Plate	Part 2	9 Mar 12	18	1706.32
Sport Heel Cradle	ASTM Standard	6 Mar 12	34	2991.41
Sport Heel Cradle	ASTM Standard	9 Mar 12	7	3138.86
Sport Heel Cradle	**ASTM Standard**	**Both Test Days**	**Average**	**3065.14**
Sport Heel Cradle	Part 2	9 Mar 12	4	2923.80
Safety Heel Cradle	ASTM Standard	9 Mar 12	4	6897.08
Military Boot Sole Assembly	ASTM Standard	9 Mar 12	9	665.69

Conclusions

As shown in Table 1, the applied force for the Spring Plate in both the Safety and Sport Models averaged approximately 1815 Newtons. The applied force for the Sport Model Heel Cradle averaged approximately 3065 Newtons. The applied force for the Safety Model Heel Cradle averaged approximately 6897 Newtons.

Also as shown in Table 1, the Part 2 testing (the tests outside the ASTM test area) results were consistent with the ASTM results, but slightly lower.

The applied force for the military boot sole assemblies averaged approximately 665 Newtons.

The Kingetics orthotic Spring Plate puncture resistance exceeded the military boot assembly by approximately three times, while the Sport Model Heel Cradle and the Safety Model Heel Cradle puncture resistances exceeded the military boot sole assembly by approximately five times and ten times, respectively.

Future Testing Requirements

While it is felt that the amount of testing conducted during the two days of testing is sufficient to support the conclusions discussed above, additional, follow up testing may be required. The testing of the Safety Model Heel Cradles must be repeated to confirm the completed test results. This will be done after some review of the testing procedure to preclude damage to the test probe. Therefore, additional testing may include, but is not limited to: additional testing of the Heel Cradles for both the Safety and Sport models; additional testing of the boot soles; and supplemental testing of the fulcrums on both the Spring Plate and the Heel Cradle of the orthotic.

It may also be necessary to test additional samples of alternate materials and compare the results of those tests against the tests of orthotics made with the current materials.